NCRP REPORT No. 99

Quality Assurance for Diagnostic Imaging

NCRP

National Council on Radiation Protection and Measurements

[For detailed information on the availability
of this and other NCRP Reports see page 238]

NCRP REPORT No. 99

Quality Assurance for Diagnostic Imaging

Recommendations of the NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS

NATIONAL INSTITUTES OF HEALTH
NIH LIBRARY
NOV 2 9 1995
BLDG 10, 10 CENTER DR.
BETHESDA, MD 20892-1150

Issued 30 December 1988
First Reprinting October 15, 1990

National Council on Radiation Protection and Measurements
7910 WOODMONT AVENUE / BETHESDA, MD 20814

QC
770
N13
no. 99
1988

LEGAL NOTICE

This report was prepared by the National Council on Radiation Protection and Measurements (NCRP). The Council strives to provide accurate, complete and useful information in its reports. However, neither the NCRP, the members of NCRP, other persons contributing to or assisting in the preparation of this report, nor any person acting on the behalf of any of these parties (a) makes any warranty or representation, express or implied, with respect to the accuracy, completeness or usefulness of the information contained in this report, or that the use of any information, method or process disclosed in this report may not infringe on privately owned rights; or (b) assumes any liability with respect to the use of, or for damages resulting from the use of, any information, method or process disclosed in this report, *under the Civil Rights Act of 1964, Sect. 701 et seq. as amended 42 U.S.C. Section 2000e et seq. (Title VII) or any other statutory or common law theory governing liability.*

Library of Congress Cataloging-in-Publication Data

National Council on Radiation Protection and Measurements.
Quality assurance for diagnostic imaging equipment: recommendations of the National Council on Radiation Protection and Measurements.
p. cm.—NCRP report ; no. 99)
"Issued December 1988."
Bibliography: p.
Includes index.
ISBN 0-929600-00-2
1. Diagnostic imaging—Equipment and supplies—Quality control.
I. Title. II. Series.
[DNLM: 1. Quality Assurance, Health Care. 2. Quality Control. 3. Radiography—standards. 4. Technology, Radiologic—standards.
WN 200 N2775q]
RC78.5.N37 1988
616.07'57—dc19
DNLM/DLC
for Library of Congress 88-25435
CIP

Copyright © National Council on Radiation
Protection and Measurements 1988
All rights reserved. This publication is protected by copyright. No part of this publication may be reproduced in any form or by any means, including photocopying, or utilized by any information storage and retrieval system without written permission from the copyright owner, except for brief quotation in critical articles or reviews.

Preface

This report addresses factors that influence production of an image. It contains the necessary information to enable the imaging physician to report the diagnostic findings to the referring physician. Some of these factors are human, others are inherent to technique and equipment. The subject of the report is quality assurance, *i.e.*, all of the management practices instituted by the imaging physician, to assure highest quality medical care, but an essential element of quality assurance is quality control. The first three Sections are concerned with quality assurance in general and the remainder with quality control in specific circumstances.

This report provides a systematic approach to procedures which can ensure that the physician and the imaging facility consistently achieve their optimal performance. This, in turn, ensures that there is optimal use of radiation and that radiation exposures to patient and staff are maintained at a level consistent with the principles of optimization of radiation protection espoused by the NCRP.

The practice has been to express the quantity of radiation as "exposure" measured in roentgens (R). Exposure is a measure of the ionization caused by the interaction of x rays in a specified mass of air at the point of interest. In the international system of units (SI), which was adopted by the NCRP in Report No. 82 (NCRP, 1985a), the unit for the quantity exposure is the coulomb per kilogram (C kg^{-1}). 1 R = 2.58×10^{-4} C kg^{-1}.

This report was prepared by Scientific Committee 70 on Quality Assurance in Diagnostic Radiology. Serving on the Scientific Committee were:

Andrew K. Poznanski, *Chairman*
Northwestern University Medical School
The Children's Memorial Hospital
Chicago, Illinois

Harry W. Fischer
The University of Rochester Medical Center
Rochester, New York

James G. Kereiakes
University of Cincinnati
Cincinnati, Ohio

Joel E. Gray
Mayo Clinic
Rochester, Minnesota

Harold L. Kundel
University of Pennsylvania Hospital
Philadelphia, Pennsylvania

William R. Hendee
American Medical Association
Chicago, Illinois

William J. Tuddenham
822 Pine Street
Philadelphia, Pennsylvania

James A. Zagzebski
University of Wisconsin
Madison, Wisconsin

NCRP Secretariat—**James A. Spahn, Jr.**

The Council wishes to express its appreciation to the Committee members for the time and effort devoted to the preparation of this report.

Warren K. Sinclair
President

Bethesda, Maryland
15 December 1988

Contents

1. Introduction 1
- **1.1** Purpose 1
- **1.2** Definition 1
- **1.3** Motivation 1
- **1.4** Costs and Benefits 2
- **1.5** Implementation 2
- **1.6** Content of a QA Program 2

2. General Concepts of Quality Assurance and Quality Control 4
- **2.1** Introduction 4
- **2.2** Approaches to Quality Assurance and Quality Control 4
  - **2.2.1** Goal 4
  - **2.2.2** Factors in Quality Assurance and Quality Control 4
    - **2.2.2.1** Human Factors 4
    - **2.2.2.2** Equipment Factors 5
- **2.3** General Objectives 5
  - **2.3.1** Accuracy in Diagnosis 5
  - **2.3.2** Minimizing Radiation Per Examination 6
  - **2.3.3** Provisions for Comfort of the Patient 7
  - **2.3.4** Communication 7
  - **2.3.5** Cost 8
- **2.4** Quality of Images 8
  - **2.4.1** Definition of Image Quality 8
  - **2.4.2** Disadvantages of Poor-Quality Images 9
    - **2.4.2.1** Incorrect Diagnosis 9
    - **2.4.2.2** Risk of Repeating a Hazardous Procedure 9
    - **2.4.2.3** Unproductive Patient Radiation .. 9
    - **2.4.2.4** Patient Inconvenience 9
    - **2.4.2.5** Increased Cost 9
- **2.5** Cost-Benefit Considerations 9
  - **2.5.1** Costs of a Quality Assurance Program 9
    - **2.5.1.1** Personnel Costs 10
    - **2.5.1.2** Test Equipment 10

2.5.1.3 Decrease in Patient Flow From Testing 10
2.5.2 Savings 10
2.5.2.1 Film and Chemical Savings 10
2.5.2.2 Less Downtime of Equipment 10
2.5.2.3 Savings of Technologist Time 11
2.5.2.4 Improvement in Patient Flow 11
2.5.2.5 Decreased Cost of Equipment Service 11
2.6 Education and Quality Assurance 11
2.6.1 The Technologist 11
2.6.2 The Quality Control Technologist 11
2.6.3 Radiology and Nuclear Medicine Residents 12
2.6.4 Practicing Radiologists 12
2.6.5 Medical Physicists 12
2.6.6 The Radiological Engineer 12
2.6.7 Nonradiologist Physicians 12
2.6.8 Untrained Operators of X-Ray Equipment 13
3. Quality Assurance—Personnel Performance and Keeping of Records 14
3.1 Introduction 14
3.2 Elements of a Personnel Quality Assurance Program 14
3.3 Activities to be Monitored 15
3.4 Establishing Policies to Guide Personnel Performance 15
3.5 Developing a Record-Keeping System to Provide an Index of Compliance 16
3.6 Analyzing the Records 18
3.6.1 Quality Assurance Committee (QAC) 19
3.7 Evaluation of the Findings and Institution of Corrective Action 20
3.8 Summary 21
4. Establishment of a Quality Control Program 22
4.1 Introduction 22
4.2 Administrative Organization 22
4.2.1 Who Does It? 22
4.2.2 Responsibility 23
4.2.3 Documentation, Recording and Correction 24
4.2.3.1 Measurements 24
4.2.3.2 Recording of Data 24
4.2.3.3 Evaluation of Charted Data and Measurements 24

4.2.3.4 Setting Standards for Variation Allowed 24
4.2.3.5 Testing Frequency and Mode of Recording 25
4.2.3.6 Methods of Interpretation, Feedback and Corrective Action 25
4.2.3.7 Repair Decisions 25
4.3 Tools Needed for a Quality Control Program 26
4.4 Beginning a Quality Control Program for Equipment 26
4.5 General Methodology of Quality Control and Diagnostic Testing 26
4.5.1 Retake Analysis 26
4.5.1.1 Factors Affecting Retake Rate 26
4.5.1.2 Methods of Retake Analysis 28
4.5.1.3 The Start-Up Effect 28
4.5.1.4 Measured vs. Actual Retake Rate 28
4.5.1.5 Factors to Record in Retake Analysis 29
4.5.1.6 Radiograph Artifacts 29
4.5.2 Recording Equipment Downtime and Failure 29
4.5.3 Exposure Per Image 29
4.5.4 Test Objects for Evaluation of Equipment Performance 30
5. Procedures, Objectives, and Policies 31
5.1 Management of Personnel Activities 31
5.1.1 Importance of Monitoring Personnel Performance 31
5.1.2 Application of Recommendations 32
5.1.3 Policy Statements 32
6. Photographic Quality Control 44
6.1 Storage, Darkroom, and Processing Conditions 44
6.1.1 Film and Chemical Storage 44
6.1.1.1 In the Vendor's Warehouse 45
6.1.1.2 In-House Storage 45
6.1.2 Darkroom Conditions 45
6.1.3 Darkroom Fog 46
6.1.4 Manual Processing 47
6.1.5 Minimum Number of Films for Automatic Processors 48
6.2 Processor Quality Control 48
6.2.1 Methods for Processor Quality Control 48

6.2.2 Aged vs. Fresh and the Type of Film for Sensitometric Strips 49
6.2.3 Photographic Processor Control Charts, Operating Levels, and Control Limits 50
6.2.4 Establishing and Maintaining a Processor Quality Control Program 51
6.2.5 Evaluation of the Fixing Process 52
6.2.6 Film Washing for Archival Quality 53
6.2.7 Processor Transport Time, Solutions and Wash Water Temperature 53
6.2.8 Water and Processor Filters, and Replenishment and Wash Water Flow Meters 55
6.3 Special Systems 55
6.3.1 Flood Replenishment 55
6.3.2 Daylight Systems 56
6.3.3 Silver Recovery 56
6.3.4 Processor Stand-by Units 57
6.3.5 Automatic Chemical Mix Systems 57
6.3.6 Systems Cleaner and Processor "Seasoning" 58
6.3.7 Miscellaneous 59
6.4 Film Copiers 59
7. Quality Control in Conventional Radiography 61
7.1 X-Ray Tubes and Collimators 61
7.1.1 Filtration 61
7.1.2 Light Field, X-ray Field Alignment, Positive Beam Limitation (PBL) Accuracy, and X–Y Scale Accuracy 63
7.1.3 X-ray Beam, Bucky Grid Motion and Centering, Image Receptor Alignment, X-ray Beam Perpendicularity, and Source-to-Image Distance Indicator Accuracy 64
7.1.4 Focal Spot Size 65
7.1.5 Visual Checks 65
7.1.6 Mechanical and Electrical Safety Checks .. 67
7.1.7 X-ray Tube Heat Sensors 67
7.1.8 Off-focus Radiation 68
7.2 X-ray Generators 68
7.2.1 Overload Protection 68
7.2.2 Peak Generating Potential (kVp) 69
7.2.3 Exposure Timers 70
7.2.4 X-Ray (Radiation) Output Waveforms 71

7.2.5 Exposure per Unit of Tube Current and Time 72
7.2.6 Linearity 72
7.2.7 Exposure Reproducibility 73
7.2.8 Phototimers 74
7.3 Grids 76
7.3.1 Grid Uniformity 77
7.3.2 Grid Alignment 77
7.4 Cassettes, Screens, Films, and Chemicals 78
7.4.1 Screens, Films, and Chemicals 78
7.4.2 Screen-Film-Cassette Speed Matching 79
7.4.3 Screen-Film-Cassette Replacement 79
7.4.4 Screen-Film Contact 80
7.4.5 Screen Cleanliness 80
7.4.6 Cassettes and Cassette Identification 80
7.5 Film Evaluation Following Radiograph of a Phantom 81
7.5.1 Exposure Per Film 81
7.5.2 Matching Images and Exposures 83
8. Quality Control in Fluoroscopic and Cine Imaging ... 84
8.1 X-ray Tubes, Collimators, and Generators 85
8.2 Exposure Rates and Exposure 85
8.2.1 Maximum Fluoroscopic Exposure Rates 85
8.2.2 Standard Fluoroscopic Exposure Rates 86
8.2.3 Spot Film and Spot Film Cameras 87
8.2.4 Cine Film Exposures 89
8.3 Automatic Brightness, Exposure, and Gain Control Systems 89
8.4 Fluoroscopic, Spot Film, and Cine Image Size and Beam Limitation 90
8.5 Fluoroscopic, Spot Film, and Cine Resolution and Distortion 91
8.6 Image Lag 93
8.7 Flare 94
8.8 Relative Conversion Factor of Image Intensifers 96
8.9 Cine Projectors 98
9. Mobile Radiographic, Capacitor Discharge, and Fluoroscopic Systems 99
9.1 Capacitor Discharge Systems 99
9.2 Mobile Radiographic Systems 100
9.3 Mobile Fluoroscopic Systems 102
10. Quality Control in Conventional X-Ray Tomography 104
11. Quality Control in Mammography 108

12. Quality Control in Dental Radiography 111
12.1 Introduction 111
12.2 Description of Quality Control Procedures for Dental Radiograph 111
12.2.1 Reference Film 111
12.2.1.1 Test Film 111
12.2.1.2 Test Radiograph 112
12.2.2 Retake Record 112
12.2.3 Effective Operation of Darkroom 113
12.2.4 Film Processing 113
12.2.5 Cassette and Screen 114
12.2.6 Viewboxes 114
12.2.7 Test of X-ray Units 114
12.2.7.1 Leakage Radiation 114
12.2.7.2 Source To End-of-Cone Distance 115
12.2.7.3 Beam Alignment and Collimation 115
12.2.7.4 Beam Quality 115
12.2.7.5 Timer 115
12.2.7.6 Exposure Switch 115
12.2.7.7 Radiation Exposure 115
13. Quality Control in Radiological Special Procedures 117
13.1 Film Changers 117
13.2 Cinefluorographic Units 118
14. Quality Control in Computed Tomography 120
15. Quality Control in Digital Imaging 125
15.1 Digital Subtraction Angiographic Imaging 125
16. Quality Control in Nuclear Medicine 128
16.1 Introduction 128
16.1.1 Care and Maintenance 128
16.1.2 Records 129
16.1.3 Film Processing 129
16.2 Radionuclide Calibrator 129
16.2.1 Test Precision 129
16.2.2 Relative Response to Reference Source 130
16.2.3 Test for Linearity of Response 130
16.2.4 Test of Accuracy 131
16.2.5 Test for Geometry Effects 131
16.3 Scintillation Spectrometer 132
16.3.1 Quality Control Test 132
16.3.2 60-Herz Test 132
16.3.3 Test of Pulse Height Analyzer (PHA) 132
16.3.4 Background Activity Check 133

16.3.5 Test of Precision 133
16.3.6 Chi-square Test 134
16.3.7 Test of Energy Calibration 134
16.3.8 Test of Energy Resolution 135
16.3.9 Test of Linearity 135
16.3.10 Counting Rate Effects 136
16.4 Nonimaging Scintillation Systems 136
16.4.1 Precision (Repeatability) 137
16.4.2 Test for Geometry Effects 137
16.5 Rectilinear Scanners 137
16.5.1 Precision (Repeatability) 138
16.5.2 Density Calibration Check 138
16.5.3 Test of Contrast Enhancement 138
16.5.4 Collimator Evaluation 139
16.5.5 Collimator Spatial Resolution 139
16.5.6 Collimator Depth of Focus 139
16.6 Scintillation Cameras 139
16.6.1 Test for Uniformity 140
16.6.2 Test for Spatial Linearity and Resolution 142
16.6.3 Relative Sensitivity 144
16.6.4 Counting Rate Characteristics 144
16.6.5 Energy Resolution 144
16.7 Imaging Accessories 145
16.7.1 Multiformat Camera 145
16.8 Single Photon Emission Computed Tomography System (SPECT) 145
16.8.1 Field Uniformity 146
16.8.2 Center-of-Rotation Determination 147
16.8.3 Pixel Sizing 147
16.8.4 Camera Axis of Rotation—Plane Alignment 148
16.8.5 Spatial Resolution 148
16.8.6 Phantoms 149
16.8.7 Testing of the Camera-Computer System 149
16.9 Xenon Trapping Systems 150
16.10 Survey Meters 151
16.10.1 Calibration 151
16.10.2 Constancy 151
17. Diagnostic Ultrasound Quality Control 153
17.1 Basic Performance Tests of Pulse-Echo Scanners ... 153
17.1.1 Geometric Accuracy 153
17.1.1.1 Phantoms and Test Objects 153
17.1.1.2 Depth Calibration Accuracy 154

17.1.1.3 Horizontal Measurement Accuracy 154
17.1.1.4 Compound Scan Registration Accuracy 154
17.1.1.5 Externally Referenced Measurement Accuracy 155
17.1.2 System Sensitivity 156
17.1.2.1 Sensitivity and Maximum Depth Visualization 156
17.1.2.2 Routine Sensitivity Checks 157
17.1.3 Image Uniformity 158
17.1.4 Hard Copy Recording 158
17.2 Higher Level Performance Tests 159
17.2.1 Spatial Resolution 159
17.2.2 Image Display Characteristics 162
17.3 Basic Tests of M-Mode Systems 162
17.3.1 Distance Calibration Accuracy and Time Markers 162
17.3.2 Sensitivity 163
17.4 Ultrasonic Doppler Systems 163
17.4.1 Ultrasound Doppler Instruments 163
17.4.2 Doppler Tests 164
17.4.2.1 Doppler signal sensitivity and noise level 164
17.4.2.2 Accuracy of flow readout 164
17.4.2.3 Range gate accuracy 165
17.5 Other Considerations 165
17.5.1 Care and Maintenance 165
17.5.2 Operator Training 165
17.5.3 Acoustical Exposure Measurements 165
18. Quality Control in Magnetic Resonance Imaging 167
18.1 Introduction 167
18.2 Quality Control Procedures 168
18.2.1 Signal-to-Noise Ratio 168
18.2.2 Spatial Uniformity of the Signal 168
18.2.3 Geometric Distortion 168
18.2.4 Slice Geometry 168
18.2.5 High Contrast 169
18.2.6 Relaxation Times 169
18.3 Quality Assurance Phantoms for Magnetic Resonance Imaging 169
19. Video Systems 171
19.1 Video Signal Levels and Line Termination 171
19.2 Television Monitors 172

19.3 Hard Copy Cameras and Visual Displays 174
19.4 Video Tape, Disc, and Digital Recorders 177
20. Computers 180
21. Miscellaneous 183
21.1 Artifacts 183
21.1.1 Artifacts From Overlying Objects 183
21.1.2 Artifact Caused by Improper Use of Imaging Equipment 184
21.1.2.1 Multiple Exposure of the Receptor 184
21.1.2.2 Grid Malfunctioning or Grid Misuse 184
21.1.2.3 Improper Film and Screen Care, Handling, Processing, and Storage 184
21.2 Mechanical Safety 185
21.3 Quality Control of the Imaging Physician's Reading Room 186
Appendix A. Summary of Quality Control Tests 188
REFERENCES 220
The NCRP 230
NCRP Publications 238
Index 247

1. Introduction

1.1 Purpose

The purposes of this report are to encourage the establishment of practical and comprehensive quality assurance programs in medical imaging facilities and to provide guidance for developing and implementing such programs. The report is designed for all health care professionals with responsibility for planning and operation of any aspect of a quality assurance program; however, it is intended primarily for practicing radiologists, other physicians and medical physicists.

1.2 Definition

Quality assurance (QA) is a comprehensive concept that comprises all of the management practices instituted by the imaging physician to ensure that: (1) every imaging procedure is necessary and appropriate to the clinical problem at hand; (2) the images generated contain information critical to the solution of that problem; (3) the recorded information is correctly interpreted and made available in a timely fashion to the patient's physician; and (4) the examination results in the lowest possible radiation exposure, cost and inconvenience to the patient consistent with objective (2).

1.3 Motivation

The objective of a quality assurance program is to ensure that the imaging physician provides the highest quality medical care possible to the patient. Quality assurance is not a new concept; it represents the essence of ethical medical practice. What is new is the concept of providing a systematic approach to procedures that will ensure, consistently, the maximum level of performance from the physician and the imaging facility.

1.4 Costs and Benefits

A quality assurance program undertaken by an informed physician, with the participation and support of the staff, is likely to contribute to improved patient care. There are, however, some associated costs. The potential benefits of a quality assurance program have been variously assessed, and the costs have occasionally been misrepresented in the literature. Section 2 presents an overview of the quality assurance concept and presents, specifically, the costs and benefits to be anticipated from initiation of a quality assurance program.

1.5 Implementation

A successful quality assurance program depends on the understanding and support of all those involved in the operation of the facility. A program initiated by management solely to comply with requirements of regulatory or certifying agencies is not likely to provide the maximum possible benefit to patient care. It is essential, therefore, that all the personnel of a facility understand the objectives of the program and are encouraged to participate actively. Section 3 deals with the development and implementation of a quality assurance program and suggests basic management devices to facilitate its acceptance and successful operation.

1.6 Content of a QA Program

A quality assurance program is a management tool that includes policies and procedures designed to optimize the performance of facility personnel and equipment.

It is difficult to monitor personnel performance by periodic testing. Human performance varies from day to day and is influenced by factors that are difficult to control. Optimization of personnel performance, therefore, depends on: (1) identifying the aspects of facility operation that require decisions or actions of facility personnel; (2) establishing policies with respect to the conduct of each of those steps; (3) encouraging compliance with those policies through education and recognition of achievement; and (4) analyzing the records of departmental operation at regular intervals.

Section 4 discusses the discrete operations and decision-making steps, notes the objectives of each, suggests policies to ensure their

proper execution, and notes types of record analysis that provide insight into the competence with which they were performed.

Standardized tests have been developed to detect deviations of equipment function from optimum performance. Such tests, carried out with care at prescribed intervals, are designed to detect slowly evolving functional abnormalities and to permit corrective action before significant deterioration of image quality occurs. They also indicate equipment malfunction before equipment breakdown occurs. Quality control, as opposed to the broader concept of quality assurance, refers to the routine performance and interpretation of such tests of equipment function, and to corrective actions taken. Quality control, as it applies to diagnostic procedures, comprises a system of monitoring, evaluation and maintenance at optimal levels of all characteristics of performance that can be defined, measured and controlled. Sections 6 to 21 of this report relate specifically to tests of equipment function. Each chapter deals with a different class of equipment. For each test the purpose, recommended frequency, materials needed for its performance, and expected results with tolerance limits are cited. Detailed instructions concerning the performance of these tests are found in the cited literature. Finally, the relative importance of each test in a comprehensive quality assurance program is evaluated. For easy reference, these data are summarized in Appendix A.

2. General Concepts of Quality Assurance and Quality Control

2.1 Introduction

Quality control and quality assurance are not well defined and are often incorrectly used interchangeably. Different individuals and agencies have devised somewhat different definitions of the two functions. Quality control is a series of distinct technical procedures which ensure the production of a satisfactory product. Its aim is to provide quality that is not only satisfactory and diagnostic, but also dependable and economic. Quality assurance is an all-encompassing program, including quality control, that extends to administrative, educational, and preventive maintenance methods. It includes a continuing evaluation of the adequacy and effectiveness of the overall imaging program, with a view to initiating corrective measures when necessary.

2.2 Approaches to Quality Assurance and Quality Control

2.2.1 *Goal*

Accurate and timely diagnosis is the principal goal of a radiology quality assurance program. The secondary goals are minimization of radiation exposure and risk and of discomfort and cost to the patient and community. However, these secondary goals must always be balanced against the primary goal.

2.2.2 *Factors in Quality Assurance and Quality Control*

2.2.2.1 *Human Factors.* A quality assurance program depends on the effort of all members of the facility staff—the imaging physician, medical physicists and radiological engineers, technologists, clerical

personnel, nurses and aides and other employees. All members of the staff must be dedicated to the concept of quality assurance and must communicate freely with each other. When the quality control of the facility's equipment is adequate, most of the problems in obtaining images of diagnostic value are the result of human error; under these circumstances the greatest good is obtained by influencing human factors. When the equipment is well controlled, for example, most images of poor quality are due to improper technique selection (under and over exposure) and positioning. Minimizing these human errors requires a commitment to quality by the imaging physician and associates, and the chief technologist and co-workers. There must be a continuing dialogue regarding the quality of images among all employees so that quality is maintained, and perhaps improved.

2.2.2.2 *Equipment Factors.* When the imaging equipment is not well controlled, it is difficult to learn whether the errors are due to personnel or equipment. It is therefore essential that equipment function properly.

2.3 General Objectives

2.3.1 *Accuracy in Diagnosis*

Procedures to assure that radiological examinations are appropriate for the clinical problems at hand are basic to quality assurance. These procedures should eliminate examinations that are frivolous, unnecessary or incorrectly requested. The imaging physician may need to limit evaluation of appropriateness of examinations to those involving greater risks, costs or complexity. For simpler, less risky and less costly examinations, *e.g.*, chest radiography, such daily prospective screening by the imaging physician may not be practical. Technologists and clerical personnel, however, should screen examination requests to be sure that: (1) they do not duplicate recent prior efforts; (2) the body parts involved correspond to the examinations requested; and (3) clinical histories are provided. If a request is thought to be inappropriate the imaging physician should, on review of the available information or in consultation with the referring physician, decide whether or not to proceed with the examination. Retrospective studies may be useful in determining the propriety of examinations for specific clinical situations. The differentiation between unnecessary duplication and repeat examinations to gauge

disease or treatment progress is the province of the imaging physician, who should be consulted when questions arise (Hillman *et al.*, 1979).

The development and evaluation of algorithms to ensure that the most direct, efficient, and economical pathway to accurate diagnosis is taken is the responsibility of all practicing physicians and is a vital element of quality assurance. The radiologist should take the leadership role by considering ways in which experience and talent, the types and availability of equipment, and other local factors including costs and risks alter the application of the algorithms to an individual patient (Eisenberg, 1984; McNeil and Abrams, 1986).

The number of radiographs considered to be optimal for an examination continues to be a subject of controversy. Quality assurance includes an effort to limit the number of radiographs and to minimize the fluoroscopic exposure time consistent with acquiring an accurate diagnosis. In addition, radiation risks and cost must be balanced against the extent and completeness of the examination. Tailoring the examination to the clinical problem is a worthwhile activity, particularly for more complex examinations where risks and costs are greater. Consensus on this problem is hampered by the scarcity of data on whether the accuracy of a standard examination is enhanced or diminished by adding other views. Underlying the whole problem is the difficulty in placing a value judgment on inaccurate diagnoses in one or more patients, when most patients are diagnosed accurately.

Medical images should generally be of the highest technical quality to permit a full range of diagnoses. The requisite quality of the image, however, may vary with the type of information needed; radiation to the patient can be reduced when maximal resolution is not required (*e.g.* see Section 2.4.1).

2.3.2 *Minimizing Radiation Per Examination*

The radiation received by the patient for a particular procedure varies considerably (FDA, 1984a). There is no universal agreement on an optimal dose for a specific examination. Generally, too small a dose may fail to record enough information to lead to diagnosis and, in this case, the patient receives unproductive irradiation. In both underexposed and overexposed films, a subtle fracture or lesion can be missed. In either case, the need to repeat the examination requires the patient to be exposed to additional radiation. The amount of radiation used in diagnostic radiology is associated with a low risk to the individual patient compared with other risks in the environ-

ment and is less hazardous than the failure to obtain a correct diagnosis (ICRP, 1982). However, an important element of quality assurance is the use of an amount of radiation that is adequate but no more than enough to produce a diagnostic image, *i.e.,* an image that allows a correct diagnosis to be made.

A quality assurance program should also strive to reduce risks other than radiation, such as those associated with the administration of intravascular contrast media or the use of needles, catheters, and accessories. The hazard of a repeat excretory urogram [*e.g.,* death from excretory urogram is 1 in 30,000 plus added morbidity with ionic contrast media—(Ansell *et al.,* 1980)] or a repeat angiogram due to nonradiation factors is much greater than the risk of additional radiation from the repetition.

2.3.3 *Provisions for Comfort of the Patient*

An important element of a quality assurance program is the effort exerted for the patient's comfort and privacy. To that end, the imaging physician and supporting personnel should respect the patient's privacy and seek to correct any deficiencies in this regard. Analysis of patient waiting time and of patients' evaluation of departmental conditions such as room temperature, comfort of equipment, and politeness and consideration of personnel are of value in this regard.

2.3.4 *Communication*

Another important quality assurance consideration is to ensure that the image from a particular patient is correctly identified, and that the interpretation of the image reaches the referring physician expeditiously. Each patient's films should be accurately identified by a marking or labeling system that suppresses errors but permits them to be easily detected. Likewise, the extremity or body side must be correctly identified as *right* or *left,* using a system that allows online checking for accuracy. The technologist is primarily responsible for the proper identification of the images. Education of the technician on the importance of proper identification is the responsibility of the supervising technologist and the attending imaging physician. The transcription of the official report onto the patient's report form should be periodically audited for accuracy. The imaging physician and the typist share this responsibility. Failure to provide this element of quality assurance may lead to unnecessary, repetitious radiation exposure and has serious medico-legal implications.

Official reports, either oral or written, must be provided speedily to be valuable in the clinical management of patients. Oral reports must be promptly followed by an official written report. The speed and constancy of flow of reports should be analyzed periodically.

The referring physician's opinion on the quality of radiologic services should be sought periodically.

2.3.5 *Cost*

The reduction of cost to the patient, department and community is an important goal of a quality assurance program. A diagnostic image obtained with a minimum of technical and clerical errors should result in a lower cost per examination. Of course, correct diagnosis should not be compromised by devotion to cost reduction.

2.4 Quality of Images

2.4.1 *Definition of Image Quality*

There are no hard and fast criteria for defining proper image quality. In theory, a quality image is one that makes accurate diagnosis feasible. Thus, the image quality needed will vary with the type of information needed. In practice, a compromise usually is made which involves choosing a system that maximizes information in specific situations, while minimizing radiation dose to the patient, the expense involved and the discomfort that may occur. However, when a radiograph is obtained for a specific purpose, an image with less than optimal definition is acceptable if it will answer the clinical problem. For example it is acceptable to use a faster image receptor for barium enema examinations than for chest radiographs. Similarly, in the follow-up radiographic examination of the spine of a child with scoliosis, the fine, detailed information necessary on the first radiograph is not necessary to evaluate changes in the degree of curvature. Hence, a very fast (low-dose) system can be used. On the other hand, if there is a question of bony abnormality in that same curved spine, or if the symptoms relate to bone pain, a more detailed follow-up study is needed. Similarly, a partially fogged radiograph of the spine in a follow-up examination is acceptable if the curvature is still visible. However, there is often disagreement about image quality needed in specific situations, because quality is perceived differently by different observers. For example, there is con-

troversy among pediatric radiologists on whether to use a fast or slow screen-film combination for neonatal chest radiography.

2.4.2 *Disadvantages of Poor Quality Images*

2.4.2.1 *Incorrect Diagnosis.* Incorrect diagnosis is the most important consequence of poor quality images. A poor image may cause the imaging physician to miss a fracture or a destructive lesion. However, small deviations in quality may not alter diagnostic ability. Incorrect diagnosis may also be the result of an improper or inadequate set of views. For example, a suspected ankle fracture may be missed if AP and lateral films but not an oblique film are obtained as part of the routine examination.

2.4.2.2 *Risk of Repeating a Hazardous Procedure.* If a procedure that has nonradiological risks must be repeated because of poor images, there is additional risk to the patient. For example, unsatisfactory radiographs in an angiographic procedure may require reinjection or even recatheterization, which have their own morbidity and mortality risks.

2.4.2.3 *Unproductive Patient Radiation.* If the image is inadequate for diagnosis, then the radiation the patient has received has no benefit.

2.4.2.4 *Patient Inconvenience.* If a procedure must be repeated because of a poor quality image, patient waiting time will be increased. If the radiograph is not checked for quality before the patient is released, the patient may have to make another visit to the radiology department.

2.4.2.5 *Increased Cost.* Repeat examinations are costly to the patient, the radiology department and the hospital.

2.5 Cost-Benefit Considerations

2.5.1 *Costs of a Quality Assurance Program*

The major reason for a quality assurance program is to optimize diagnosis and, hence, patient care. However, the costs of that program must be recognized to ensure that the benefits warrant the costs.

2.5.1.1 *Personnel Costs.* Specific duties in quality control of equipment may be delegated to specific individuals, usually medical physicists or technologists, or various combinations of both. Their quality control duties are time consuming, and the cost of these functions must be included in determining the efficacy of the program.

2.5.1.2 *Test Equipment.* The cost of test equipment is a small fraction of the total capital budget of a radiology department. Such equipment must be available if quality control functions are to be performed effectively.

2.5.1.3 *Decrease in Patient Flow from Testing.* If all of the testing is done outside of usual daytime hours it will have little effect on patient flow. If the testing must be done during the normal work day and the use of the imaging equipment for patients is thereby limited, testing may decrease the flow of patients, and thus may involve a cost.

2.5.2 *Savings*

The basic purpose of a quality control program is improvement in the quality of medical care. In some situations, a monetary savings can also be realized. For example, Barnes *et al.* (1976) reported a savings of $27,000 (in 1976 dollars), excluding personnel costs, resulting from the implementation of a quality control program in a radiology department with 49 x-ray tubes. The new cost savings will be greatest in facilities that have not previously been well maintained. The primary cost saving of a quality assurance program is the result of a decrease in repeat studies.

Although the number of repeat examinations can be reduced by a quality control program, a large fraction of repeats are the result of technologist decision. The quality assurance program should seek to affect the decision-making process at this level.

2.5.2.1 *Film and Chemical Savings.* Film savings realized by decreased repeat examinations may be partially offset by the number of films used in quality control functions; however, the number of films used in quality control is usually smaller than the number used in repeat examinations.

2.5.2.2 *Less Downtime of Equipment.* Although most breakdowns are sporadic and unpredictable, the amount of downtime due to component failure in general may be significantly decreased by a quality control program. Certainly, breakdowns can be, in some

cases, diminished by an effective preventive maintenance program and may be avoided by quality control techniques.

2.5.2.3 *Savings of Technologist Time.* Repeat examinations cause unnecessary use of technologist time, and decreasing repeats will make more efficient use of technologists and equipment.

2.5.2.4 *Improvement in Patient Flow.* An increase in the number of patients requiring examination for valid medical reasons can result in an increased return on the capital investment.

2.5.2.5 *Decreased Cost of Equipment Service.* If the source of an image quality problem can be identified by facility personnel, the resultant service call will be less costly because troubleshooting time will be reduced or eliminated.

2.6 Education and Quality Assurance

Human factors are of utmost importance in quality assurance, and therefore personnel education should be continuous. Training should be directed at all facility personnel.

2.6.1 *The Technologist*

Positioning of the patient and exposure control are the responsibility of the technologist. These factors largely determine whether an image will provide the required diagnostic information. Stimulating the technologist to strive for high-quality images on the first attempt is the most important goal of education in a quality assurance program. Care must be taken that the technologist is not encouraged to repeat examinations to produce a better image when the original is diagnostically satisfactory. The technologist must also take great care that the images obtained are properly marked and identified.

2.6.2 *The Quality Control Technologist*

The quality control technologist needs to have adequate training in various aspects of quality control. Such training may be given in-house by imaging physicians, medical physicists, and radiological engineers. There is also an advantage to individual participation in specialized training in quality control, *e.g.*, processor quality control.

2.6.3 *Radiology and Nuclear Medicine Residents*

The training program for radiology and nuclear medicine residents should include material on quality assurance and quality control. In a teaching hospital, residents often make the decisions on whether the images are satisfactory for diagnosis and what factors may need to be altered for improvement. More importantly, the residents must be educated on methods and techniques for obtaining high-quality images before they begin their own practices. Examinations by the American Board of Radiology and the American Board of Nuclear Medicine should include appropriate material on the fundamentals of image generation, quality control and quality assurance.

2.6.4 *Practicing Radiologists*

It is the responsibility of the radiologist in charge, and associate radiologists, to maintain quality assurance in their departments and to be knowledgeable in this area. Attending refresher courses in quality assurance and interaction with medical physicists and technologists are possible approaches to increasing radiological knowledge.

2.6.5 *Medical Physicists*

Medical physicists should be responsible for the practical aspects of diagnostic radiology, including quality control. The medical physicist's teaching obligations should reflect this practical involvement.

2.6.6 *The Radiological Engineer*

Some time should be allocated to in-house radiological engineers for continuing education on equipment maintenance. Such courses are frequently available from manufacturers on maintenance of specific equipment for which the radiological engineer is responsible.

2.6.7 *Nonradiologist Physicians*

Many radiologic examinations are performed in offices and clinics and hospital departments controlled by individuals who have insufficient training in radiation protection and in factors affecting image quality. It has been the almost universal observation that facilities

producing these examinations could benefit from a quality assurance program. Individuals with little knowledge about quality in diagnostic imaging, are not equipped to teach and guide the operators of their x-ray units, particularly when the operators are not themselves trained technologists. It is important that knowledge of quality assurance be acquired through specialty board examinations of these physicians. Progress in this matter has been achieved through state regulations which permit operation of radiation-emitting equipment only by individuals trained in radiation protection, or which require physicians operating a radiation-emitting unit to pass a state examination on radiation protection or to be board certified in radiology or diagnostic radiology.

2.6.8 *Untrained Operators of X-Ray Equipment*

Often the individuals operating x-ray equipment in private offices and clinics are untrained and therefore have little knowledge or understanding of the technical factors to be used for obtaining diagnostic images, or of radiation protection. Such individuals should not operate x-ray equipment. Evidence for adequate training must be documented and retained on site by operators of equipment.

3. Quality Assurance—Personnel Performance and Keeping of Records

3.1 Introduction

In an attempt to limit the exposure of the public to ionizing radiation resulting from diagnostic imaging procedures, it is as important to assure the competence and proficiency of imaging facility personnel as it is to monitor the proper functioning of imaging equipment. However, it is more difficult to assure the adequacy of personnel performance than it is to assure the proper functioning of equipment.

In general, it is reasonable to assume that in a repetitive operation there will be minimal variation in equipment function over a finite period of time. Hence, if equipment is shown to function satisfactorily at one point in time, it may be presumed: (1) that it will continue to function satisfactorily for some ensuing period; and (2) that periodic performance tests will suffice to detect malfunction before it can progress to represent a hazard to patients or degrade the diagnostic image. This premise underlies the periodic testing of equipment that forms the basis of most quality control programs.

The performance of human beings, on the other hand, is influenced by many factors. Periodic performance testing of personnel is of limited value in determining the overall level of proficiency. Some means must be found to provide a continuous, ongoing overview of personnel performance. This requirement implies that records must be generated that, for each patient examined, provide an index of personnel performance with respect to individual patients and the examinations. Periodic review of such records provides insight into the overall level of personnel performance which no periodic test can offer.

3.2 Elements of a Personnel Quality Assurance Program

The elements of a program to assure the proficient performance of imaging facility personnel include:

1. Identification of personnel activities to be monitored.
2. Establishment of policies setting forth the method of performing these activities. (Such policies should provide explicit guidance concerning the person responsible for specific activities, the way tasks are to be performed, the way decisions are to be made, and the way personnel are to relate to patients.)
3. Institution of a system of record keeping to provide objective evidence of personnel performance. These records can be maintained in a log book or in a computerized data base. They will hereafter in this report be referred to as logs.
4. Establishment of a system for the regular periodic review and analysis of such records, for determining whether or not performance as revealed by such analysis has been adequate, and for instituting corrective action if deficiencies are found. The detail of the review depends on the form and complexity of the practice and will be different in different institutions.

3.3 Activities to be Monitored

Before establishing explicit policies with respect to personnel performance, it is necessary to analyze the activities of the facility indicating the duties and participation of personnel with respect to each identifiable aspect of facility operation. This analysis may be facilitated by developing flow charts that trace the progress of the patient, the diagnostic image, and the records of the examination and facility personnel during the course of an imaging procedure. Although facilities vary, in general, the activities of any imaging unit can be grouped under the following broad headings:

1. patient scheduling
2. patient reception
3. patient preparation
4. patient examination
5. film processing
6. image quality control
7. image interpretation
8. report preparation (dictation, transcription)
9. report distribution
10. file room operation

3.4 Establishing Policies to Guide Personnel Performance

The object of policies governing personnel performance is to provide specific guidance to facility personnel. Policies adopted should

be tailored to the individual facility. An office or clinic performing only chest radiography need not establish policies concerning advance preparation of patients; whereas, a hospital facility performing contrast studies needs policies with respect to the instructions to be given to the patient, the person responsible for instructing the patients and the sequence in which contrast media studies are to be performed. The important point is that clear, concise policies should be established governing every aspect of the facility's operation that might reasonably be expected to contribute to high-quality performance. In general, the fewer policies adopted the more likely the success of the program.

Suggestions for specific policies relating to each of the generic types of activities identified in Section 3.3 are presented in Section 5.

3.5 Developing a Record-Keeping System to Provide an Index of Compliance

Records of importance to a quality assurance program are of two types: (1) objective—records that answer questions such as "How long?" "How often?" and "How many?" and (2) subjective—records that, for example, provide insight into the feelings patients have about their treatment.

One barrier to the development of a productive quality assurance program is the perception that such a program is unduly burdensome. It is important in developing a record-keeping system to minimize, insofar as possible, the burden of added record keeping. This can be achieved by entering whatever additional data may be necessary on records that are generated for other purposes. Thus, in most facilities some pertinent data are already recorded on the request form. These include demographic data concerning the patient, the type of study requested, the indication for the study, and, in many facilities, the orders written by the imaging physician (or designate) for specific exposures to be made by the technologist. Such data permit an analysis of the requested study to determine whether it is appropriate to the indication cited; whether, in fact, an adequate indication was provided; whether the projections ordered by the imaging physician were appropriate given the stated indication, the patient's age, etc. Additional data such as patient arrival and departure time can be added to such a document to increase the number of aspects of facility function that can be evaluated by a review of the completed form. (Automatic clocks that stamp the time on papers greatly simplify the problem of documenting temporal information

such as arrival and departure times.) Similarly, the time at which an interpretation was dictated, the time at which the dictation was transcribed, and the time at which the report was dispatched to its destination (the chart, the physician's office, the record room, etc.) can be recorded on the copy of the report retained in the facility. Such data are essential in detecting and controlling unwarranted delay in the preparation and distribution of hard-copy reports.

Five types of records, all of which serve other useful functions, suffice to preserve almost all of the data essential to a quality assurance program (other types of records may achieve the same end). These types of records are:

1. The *request form* contains much information as noted above. It should be preserved in the patient's image envelope, along with a copy of the report of the study to which it relates.

2. The *room log* is a permanent record of the daily activity of a given examining room. At the completion of each study, the technologist should record the following in the log: the name of the patient, the study performed, the films exposed in the case of a radiographic study, the reason for a retake if the study is repeated, the reason for any supplemental views requested, the time the study was started and completed, the date and the technologist's name (initials). If an examining room is out of service, this should be noted together with the reason. Analysis of such a record provides a useful overview of the technical aspects of facility function. A log should be maintained for every darkroom as well as for every examining room.

The room log may have value not only for quality assurance purposes, but as a medicolegal document, and in planning the distribution of work loads. Technologists should be taught that maintenance of the log is as much a professional responsibility as the performance of an imaging study, and supervisors should scan the record daily to ensure that it is properly kept.

3. The *report of the interpretation of an imaging study* is an important document, the retention of which is mandated by law in most jurisdictions. It is an important quality assurance record in the sense that the written interpretation of the imaging study may be compared with the surgical, histologic, or endoscopic findings. This provides the most useful index of the diagnostic accuracy of the facility's professional staff. As noted above, other data useful to quality assurance review can be incorporated in this report, a copy of which should be retained, usually in the envelope with the diagnostic images of the patient. In some circumstances, it is desirable to preserve an additional file copy apart from the image envelope.

4. The *incident report* is a written account of any untoward occurrence involving a patient or facility employee. Hospitals require the

preparation of such reports, and a copy should be kept in the imaging department for quality assurance, medicolegal and other purposes. In a nonhospital setting, there may be no outside requirement that such forms be completed, but the prudent imaging physician will insist that such written reports be prepared and kept on file in the facility. Reports of adverse reactions to contrast media are, in effect, a special form of incident report and should be prepared, and a copy should be preserved in the facility just as are other incident reports. Review of the incident report file provides insight into the nature and frequency of untoward events and may call attention to the need for corrective action to prevent recurrences.

5. The *patient's film jacket* or image envelope is, of course, also an important record for quality assurance review. It permits analysis of the management of a patient's imaging studies over time, analysis of whether studies were ordered in the most efficacious sequence, etc. The patients film jacket or image envelope should be retained in the facility for as long as practicable, though it is not mandated by law in some jurisdictions.

Other records that may be of value in a quality assurance program, or that may be kept as a matter of convenience or special interest, include daily work schedules, a separate arrival/departure log, questionnaires designed to elicit expressions of patient or referring physician satisfaction (or dissatisfaction), and special logs designed to monitor specific activities in greater detail than the records suggested above.

The reject film count is another indication of quality assurance. It is further discussed in Section 4.5.1.

The records suggested above will not provide insight into the efficiency of the image file room. The most reliable way to assess the performance of the file room staff is simply to request randomly selected records (image envelopes) periodically. This approach provides information about the frequency with which records can or cannot be located and the time required for record retrieval. Investigation of the contents of the retrieved envelopes will provide information concerning whether or not images and reports are being filed correctly.

3.6 Analyzing the Records

Having established the records to be maintained for analysis purposes, the next step is to determine the method of review and analysis, the means for dissemination among the staff of the facility, the

individual responsible for overseeing the program and, most importantly, for assuring that corrective action is taken when indicated.

The mechanisms established for conducting audits of performance records, for identifying areas of deficiency, and for instituting corrective action must be tailored to the individual facility. The individual responsible for the operation of the quality assurance program should establish a schedule and assign staff personnel, in rotation, to perform reviews of various aspects of facility operation and to report their findings as part of a regular staff meeting, written minutes of which should be maintained.

There are no established standards with respect to the frequency with which particular reviews should be conducted. However, periodic reviews of diagnostic errors in image interpretation and facility operation (reception/scheduling, imaging technique, report generation, file room function, etc.) should be conducted. Subsequently, areas in which problems are demonstrated should be reviewed more often than those in which performance appears satisfactory.

The method chosen to analyze the available data is best left to the individual facility. Concerns common to all facilities, the answers to which should be sought in planning reviews include the following:

- How long does it take to complete a study (patient arrival to patient departure)? This, of course, varies with the type of study performed, and it will be necessary to establish facility norms for various studies.
- What fraction of images are repeated for technical reasons, and what are the specific reasons for image rejection?
- What effect have equipment performance problems had on image quality or patient exposure?
- How long does it take to get a report of an imaging study dispatched to its destination? Are there delays in dictation, transcription, verification, or distribution?
- How frequently do reportable incidents occur? Are they related; is there a common cause?
- What fraction of requested image envelopes cannot be located?
- How long does it take the file room staff to retrieve the images of a current case?
- In what fraction of cases is no history or indication for an imaging study provided?
- What are the causes of high individual abnormal dosimeter readings?

3.6.1 *Quality Assurance Committee (QAC)*

In a large facility, a quality assurance committee (QAC) may be appointed to oversee these activities, or a single individual may be

charged with the responsibility. This is not to suggest that one individual must conduct all of the audits. On the contrary, the program will be most effective and most informative if the entire staff, including senior technical personnel, participate; however, one individual should be identified to be ultimately responsible for the conduct of the program.

In a moderate- to large-sized department, the presence of a QAC can help to stimulate interest in quality control. The QAC should be composed of the chief imaging physician or another imaging physician whose responsibility is quality control, the medical physicist, chief technologist, quality control technologist, and any other individuals who may be involved in the quality control function. The quality assurance committee ideally would meet at regular intervals to discuss problems in quality assurance and control, whether they entail administrative problems, equipment problems, or specific problems of quality control with a specific piece of equipment. A QAC helps to raise the awareness of the importance of quality assurance in the department and improves the interaction of various department members involved with this function.

3.7 Evaluation of the Findings and Institution of Corrective Action

One of the difficulties in evaluating quality assurance programs is the lack of universal standards. Although some local standards have been reported (MacEwan, 1982), there are no established limits on how long it should take to perform a lumbar spine study or to get a report to the patient's chart. There are published values on the fraction of radiographic images that are rejected for inadequate exposure technique. They vary so widely, however, that they are of little value in assessing the performance of a particular facility. The facility's staff, therefore, must judge the adequacy of its performance almost exclusively by comparison with its own previous performance. In successive reviews of a given function, any evidence of deterioration of performance should suggest prompt corrective action. Even if performance appears not to have changed, the possibility of improvement through some new effort should still be considered. Each facility will need to set its own standards of performance.

A mechanism should be established to assure that corrective action is taken when necessary. In a large facility with many individuals, it is surprisingly easy for decisions with respect to changes in policy, redistribution of assignments, or other corrective measures, to be

forgotten in the press of daily activity, never to be implemented. It is, therefore, suggested that, as part of each quality assurance presentation, the recommendations of previous deliberations be reviewed, and that documentation of the meeting show that recommended action relative to a particular problem has been implemented.

3.8 Summary

A quality assurance program is a management tool to help physicians and their supporting staffs conduct the process of diagnostic imaging with the greatest possible effectiveness and with the least possible hazard and inconvenience to the patient. A successful program depends upon the establishment of unambiguous policies with respect to the performance of the various aspects of facility operation and upon the maintenance of records sufficient to permit periodic review of how well various functions are being performed. Most of the records needed for successful quality assurance are already being generated for other purposes and a few additional entries suffice for most performance analyses.

A quality assurance program is not a series of unrelated analyses performed to satisfy some regulatory body. It is a broad coordinated program, extended in time, in which each record review contributes to overall management. At the same time, it must be remembered that the ultimate role of the physician is care of patients, not keeping of records. The program should help in the care of the patients. The quality assurance program should not be allowed to become so demanding that the staff is distracted from its primary tasks. By simplifying data collection and distributing the analysis of data among the entire facility staff, such a program can be made a valuable guide to improved operation, which may yield tangible benefits without becoming burdensome.

4. Establishment of a Quality Control Program

4.1 Introduction

Quality Control is an integral and most tangible aspect of quality assurance. Quality Control, as defined in this report, is a series of distinct technical procedures which ensure the production of a satisfactory product. Four major steps are involved.

1. *Acceptance testing*. Detection of defects in equipment that is newly installed or has undergone major repair.
2. *Establishment of baseline performance* of equipment.
3. *Diagnosis of changes* in equipment performance before they become radiologically apparent.
4. *Verification of correction of causes of deterioration* in equipment performance.

4.2 Administrative Organization

4.2.1 *Who Does It?*

Quality control activities are the responsibility of all members of a facility, but the ultimate responsibility rests with the imaging physician in charge, and responsibility for the technical aspects rests with the medical physicist. The degree of involvement of other members of the facility will vary depending on the size and organization of the facility. In larger facilities, the responsibility for specific quality control functions is likely to be delegated to one or more individuals who may be medical physicists, special quality control technologists, radiological technologists, or engineers. In the larger facilities, there may be some advantage in having one or more technologists or individuals share the quality control duties so that someone is always available to perform this function. Medical physicists have an important role in supervising and consulting with quality control technologists, and may, depending on the size of the facility, be full

time or on a consultant basis. In a smaller facility, the duty of quality control often falls upon the chief technologist, who can be supervised by either the imaging physician or a medical physicist. In still smaller facilities, the imaging physician may be the only person actually involved in this activity. It is generally impractical, in most facilities, to have each technologist totally responsible for the quality control of individual rooms, since, to do this, each technologist must be trained in the use of test tools. Although each technologist should be involved in quality control, specific tests are usually performed more effectively by individuals who have received special training and are proficient in quality control and troubleshooting procedures.

When a technologist or other individual is assigned to quality control procedures, that individual must have adequate time to perform the functions. In some busy facilities, this function may have to be done at times outside of normal working hours. The quality control technologist should be responsible directly to the physician in charge.

A medical physicist or radiological engineer should be available in house or on a consulting basis to discuss problems found by a quality control technologist and to perform any of the tests that may require invasive measurements on the equipment. Quality control is therefore done by all of these individuals together. It is important that the individual responsibilities are delineated.

In summary, in most situations, a quality control technologist carries out the day-to-day measurements in the programs and maintains quality control logs. The medical physicist oversees the program, serves as a consultant on problems encountered by the quality control technologist, and performs some of the more complex evaluations. The service engineers, either in-house or from an equipment company, carry out the repairs, preventive maintenance and calibration on the diagnostic imaging equipment. The technologist must verify the integrity of the equipment after a service engineer has completed the work.

4.2.2 *Responsibility*

The physician responsible for the unit is ultimately responsible for the quality control function. It is the user's responsibility to make certain that the equipment is working properly and safely and producing images of optimum quality. Quality control in a facility is the responsibility of the clinical service and not of advisory or regulatory agencies.

4.2.3 *Documentation, Recording and Correction*

4.2.3.1 *Measurements.* Measurements obtained by the quality control technologist or other individuals should be clearly documented and be readily available for evaluation.

4.2.3.2 *Recording of Data.* The data recorded should be charted as data points on a control chart (Gray *et al.*, 1983) at the time the measurement is made. It is often on the control chart that trends can be discovered and abnormal functions detected even before control limits are reached. In that way, a determination can be made as to whether excessively light or dark radiographs are due to problems with the output of an x-ray tube (*e.g.*, kVp, mA, or exposure time) or with the performance of the film processor. Control charts also help to determine variations between equipment (*e.g.*, the difference in radiation output from the various generators for a given mA and kVp) or differences between the processors in the facility. Similar record-keeping requirements should be used for the other modalities discussed in this report.

4.2.3.3 *Evaluation of Charted Data and Measurements.* It is obviously not enough simply to record the measurements that may be obtained and to plot them. The results must be evaluated immediately upon recording the data and corrective action taken if indicated.

4.2.3.4 *Setting Standards for Variation Allowed.* Upper and lower control limits must be determined. If these are reached or exceeded, corrective action is required. These control limits can apply, for instance, to the limits in acceptable density for a sensitometric strip or the limits on radiation emitted at a certain mA and kVp setting of a machine.

The upper and lower control limits should be established so that the diagnostic value of the image will not be significantly compromised before the limits are reached and corrective action is required. The control limits and operating levels should be established with several points in mind:

(a) limits should be set to indicate equipment problems *just before* diagnostically significant changes are evident in the clinical image, but not so restrictive as to require frequent corrective action unless real problems exist,

(b) control limits should not be so restrictive that they exceed the capability of the equipment, and

(c) control limits and operating levels may be adjusted based on experience and may be set closer to the operating level for equipment

used over a limited range or for limited applications *e.g.*, for x-ray generators used over a limited range of kVp and mA, the control limits for kVp may be reduced.

In setting the control limits, remember that limits that are set too close to the operating level will result in:

(a) increased service calls,
(b) increased downtime for service and quality control tests,
(c) increased operating cost, and
(d) decreased patient flow.

Control limits should be set by the imaging physician and medical physicist in consultation with the quality control technologist and radiological engineer. The control limits and operating levels should be reviewed periodically and adjusted if necessary.

4.2.3.5 *Testing Frequency and Mode of Recording* Variations in equipment performance are conveniently recorded on control charts and in log books. In determining the frequency and mode of recording, a balance has to be reached between the cost of performing the tests, including the disruption of departmental activity, and the benefit in improvement of quality that is produced by them.

These will vary with the different types of equipment, the importance of each of the modes tested, and the experience with particular equipment. For example, film processing quality should be tested daily. On the other hand, focal spot size may not need to be tested except in acceptance testing. In one survey,[1] no change in focal spot size was seen over a period of eight years for 180 x-ray units except just before a tube failed. More details about recommended frequency and mode of recording are included in the appropriate sections and in Appendix A.

4.2.3.6 *Methods of Interpretation, Feedback and Corrective Action.* Formal means should be established for interpreting the recorded data. There should be a standard procedure for reporting significant problems to service personnel. When a piece of equipment has been repaired, it should be inspected to assure that the problem has been corrected and this fact should be documented.

4.2.3.7 *Repair Decisions.* Responsibility should be fixed for initiating the repair of equipment. This will vary for each institution and will depend on the knowledge and responsibility of the various individuals.

[1]Personal communication from Joel Gray at Mayo Clinic.

4.3 Tools Needed for a Quality Control Program

The actual equipment that will be needed for a quality control person will depend on several factors, including the size of the facility and the expertise of individuals who carry out the tests, as well as the scope of the testing program. The tools needed for a quality control program are indicated in the tables in Appendix A.

The costs of the equipment will vary, but even the cost for items listed in Appendix A is a small part of the total capital investment of a large imaging facility.

4.4 Beginning a Quality Control Program for Equipment

The quality control program begins before the equipment is purchased. There should be a survey of the facility to determine the type of equipment needed before purchase, and time should be allotted for selecting equipment and preparing specifications. The development of precise specifications for equipment and the inclusion of the specifications in the purchase contract is probably the most important portion of the equipment purchase activities. In addition, it is worthwhile to obtain quotations for service costs over the expected life of the equipment before signing a purchase agreement. After the equipment is installed, it must be checked to determine that it meets the specifications. Also, users must be instructed in proper operation and trouble shooting techniques. This acceptance phase sets the baseline for the subsequent quality control functions.

4.5 General Methodology of Quality Control and Diagnostic Testing

4.5.1 *Retake Analysis*

Since one of the important goals of a quality control program is to decrease the number of radiographs that need to be repeated, analysis of the number of retakes is an important part of any quality control program.

4.5.1.1 *Factors Affecting Retake Rate.* The retake rate of an institution is highly variable and depends on many factors, not all related

to quality. If the standards of an institution are low, there may be almost a zero rate of repeat films. Yet other individuals viewing these radiographs would consider them useless for diagnostic purposes. In other situations, there may be overemphasis on radiograph quality, and the repeat examination rate may be extremely high, even though some radiographs that were repeated would have been accepted by many other institutions. Therefore, it is difficult to compare the repeat rates among institutions.

The published retake rates in one review varied from 2.7 percent to 6.1 percent (Levy and Escamilla, 1979), although there is evidence that it may be 13 percent to 15 percent in other institutions (Hall, 1977). The rate of retake is also dependent to a large degree on technologist experience. For example, in a children's hospital, evaluations by Der-Vartanian (NCRP, 1981) showed a retake rate of 4.1 percent for experienced technologists and 7.7 percent for student technologists. The difference was greatest for errors due to positioning, where the retake rates for students and technologists were 2.4 and 0.7 percent, respectively.

The distribution of retakes can reveal the pattern of retakes for individual technologists. For example, if a technologist is found to have a higher than normal percentage of overexposed films, then that problem can be addressed. If a technologist has difficulty with one aspect of radiography, *e.g.*, positioning, then specific instruction should be provided. However, there may be a valid reason for a greater than expected number of retakes by a technologist. For example, in an analysis of retakes by Goldman *et al.* (1977), two technologists were shown to have a higher proportion of repeats because of patient motion. These individuals worked primarily during off-peak hours and, because of this, encountered more difficulty in obtaining the cooperation of patients. In such a situation decisions must be made as to whether additional personnel are needed to help control the patients, different techniques need to be developed to deal with such patients, or the greater need for retakes should be accepted.

Quality control procedures can decrease the repeat rate. Hall (1977) found that some facilities had an initial average reject rate of 13 percent of radiographs, which was reduced to 7 percent after establishment of quality control programs. In one children's hospital, when a new chairman arrived, the repeat rate was 12 percent. After the institution of a quality assurance and control program, it was reduced to 5.1 percent. In that hospital, errors in technique accounted for 87 percent of the total number of repeats (54 percent because the radiographs were too light and 33 percent because the radiographs were too dark). Although part of this was corrected by quality control measures, further improvement was possible only after moving to a

new facility with new equipment[2] giving lesser variation in exposure (reduced from 5.1 percent down to 2.8 percent).

4.5.1.2 *Methods of Retake Analysis.* The number of retakes can be estimated from a room log, but it may be inaccurate. A formal retake analysis is a time-consuming and complicated procedure. It requires an actual count of the radiographs that need to be repeated; for a statistical evaluation, there should be at least a thousand exposed radiographs in a sample (Gray *et al.*, 1983).

Practically, such an analysis is difficult in an x-ray facility. Retake evaluation should be performed in a way that interferes minimally with normal operations. An individual can be assigned to spend time performing this function, or the technologists can be asked to retain their rejected radiographs and then retrospectively determine why they were repeated. Although the second method is somewhat easier, it may be difficult later on to determine the reason for rejection, and the repeat rate may be underestimated. If all radiographs (including poor radiographs) are given to the imaging physician for interpretation, a rough idea may be obtained of problems existing in the department, and a retake rate evaluation may be less important. It is also important to evaluate how many repeat or rejected radiographs were actually acceptable and should not have been repeated. Since the benefits of a retake analysis depend on their cooperation, the technologists must be assured that the retake analysis is part of the departmental quality control program and is designed to help improve the quality of their work, rather than to punish them for wasteful practices.

4.5.1.3 *The Start-Up Effect.* There is often a start-up effect on retake studies which may be associated with a much higher or much lower retake rate (Goldman and Beach, 1979). The effect apparently disappears after two to four weeks and is followed by stabilization at a particular level. This peculiar effect may be due to initial stress to the system or an increased awareness of quality, which may cause some films to be rejected that would have been previously passed as marginal. There may also be a change in motivation of the technologists because their efforts are being more closely monitored.

4.5.1.4 *Measured vs. Actual Retake Rate.* Because of human factors, not all of the retakes are recorded in many retake evaluation programs. For example, in the study of a metropolitan hospital

[2]Personal experience from A.K. Poznanski *et al.* at Children's Memorial Hospital in Chicago.

described by Burnett *et al.* (1975), scrap film was counted, and it was determined that only 58 percent of retakes were recorded by the technologist. Furthermore, a check of total examinations in that particular study found that only 75 percent of the examinations were recorded.

4.5.1.5 *Factors to Record in Retake Analysis.* When performing a retake analysis, a form should be devised to record the reasons for rejection, including: patient positioning, patient motion, radiographs too light, radiographs too dark, artifacts, fog, processor faults. Some retakes may be needed for medical reasons. A lack of correct clinical information, for example, may require a retake. Retakes caused by improper or deficient information on the patient request form would not be improved by quality control procedures but are still important to identify, although they should be excluded from the count.

4.5.1.6 *Radiograph Artifacts.* This includes artifacts due to processing, static, grid cut-off, cassette light leaks, fogging, and dirty cassettes. These are further discussed in Section 21. These factors do not always require a repeat examination, depending on whether the artifact, by its location or character, interferes with making a diagnosis. Grid misalignment, for example, may cause an uneven density in the radiographs, but frequently, unless it is severe, a repeat examination is not required.

4.5.2 *Recording Equipment Downtime and Failure*

There is an advantage of having a log book for each radiographic room, listing the problems that have occurred in that room. This is particularly useful for identifying transient problems that may not be serious, and yet, when a pattern develops, indicate the need for correction. Also, this record gives a clearer picture of the percentage of time the machine is not functioning or is malfunctioning and why. The record should also include the length of time for vendor or service personnel to respond to the call and repair of the equipment. Also, note should be made of the time required to obtain spare parts when an experienced serviceman was called. This record should be reviewed when decisions are made to purchase additional or replacement equipment. In addition, these data can be a valuable measure of the cost effectiveness of the equipment and the vendor's service.

4.5.3 *Exposure Per Image*

The radiation exposure should be measured for the standard procedures done in each room and recorded in the room quality control

log. Knowledge of these exposures is useful in a comparison of exposures within the facility. A summary table containing the exposure for specific examinations in each room in the facility should be prepared in order to obtain a concise overview of actual exposures and exposure variation throughout the facility. If exposures in one room are higher or lower for a specific examination than in others, the reason should be determined and explained. This record also permits comparison of the exposures in one facility with those in others.

4.5.4 *Test Objects for Evaluation of Equipment Performance*

An evaluation of the quality of radiographs should be done using patient-simulating phantoms as well as other test objects or phantoms, particularly when making a decision about changing imaging techniques. Care should be taken to select phantoms which simulate the patient in terms of attenuation as well as anatomical shape.

5. Procedures, Objectives, and Policies—Performance Optimization

5.1 Management of Personnel Activities

In this section, the various steps in the production and interpretation of a diagnostic image, including the attendant patient handling procedures, are identified. Policies designed to optimize performance at each of these steps are proposed, and periodic record reviews are suggested to provide an indication of the competence with which the various aspects of facility operation are being conducted. Deficiencies detected by such reviews permit the responsible physician to modify procedures, to call deficiencies to the attention of responsible employees, or to institute additional controls.

5.1.1 *Importance of Monitoring Personnel Performance*

The activities discussed in this section are largely administrative in nature, and may appear irrelevant to the concept of quality assurance as it is usually defined. Moreover, the consideration of these administrative matters may appear unrelated to the primary objective of the NCRP, *i.e.*, the reduction of unproductive irradiation of the public. The inclusion of these matters here, however, is, in fact, entirely consistent with the concept of quality assurance as a comprehensive management tool designed to assist the imaging physician in providing diagnostic service of the greatest possible benefit to the patient at the least possible cost measured in terms of patient irradiation, discomfort, inconvenience and expense. Moreover, it is emphasized that most errors that result in unproductive patient irradiation are related to the procedures discussed in this section. Improper scheduling, preparation or gowning of the patient; the performance of inappropriate or inadequate examinations; errors in image exposure, identification or processing; delays in image interpretation and inability to retrieve images when required—these are the principal causes of repetitive imaging and hence of unnecessary

patient exposure, and precisely the problems of facility operation with which these policies are concerned.

5.1.2 *Application of Recommendations*

The policies and procedures employed in any given facility must be tailored to the needs and capability of that individual unit. Very large departments may require more rigorous quality assurance techniques because of their organizational complexity and the problems of communication associated with a large, dispersed staff. A small facility with relatively few workers may not require as formal a system of management as is here proposed. All facilities, whatever their sizes, must deal with essentially the same succession of events in providing diagnostic imaging services and should, formally or informally, establish policies with respect to the handling of these events. Some periodic internal review should be conducted to ensure that the quality of service is maintained at an adequate level.

5.1.3 *Policy Statements*

Examples of policy statements designed to guide facility personnel in the performance of their duties are presented below.

EXAMPLE A

Procedure: Acceptance of request for an imaging study

Objective: Request for imaging studies shall be checked against previous patient registration records to detect repetitive requests for service. If a request appears to be redundant, the imaging physician in charge shall determine whether or not the study is indicated.

Comment: In many facilities and particularly in large, acute care, teaching hospitals, repetitive requests for the same imaging study may be received within a relatively brief period. Sometimes such requests are legitimate and reflect the clinician's need to monitor the critically ill and unstable patient frequently. At other times, duplicate requests for service are generated by different members of the patient care team and repetitive examination of the patient is neither necessary nor desirable. The receptionist who in most facilities has access to records of previous imaging studies (via computer or patient record cards) should identify repetitive requests for service and bring them to the attention of the imaging physician who should

either determine the necessity for a repeat study or obtain additional information to assist in the decision.

Control: Periodic review of randomly selected patient image files indicates the frequency with which duplicate studies were unnecessarily performed.

EXAMPLE B

Procedure: Scheduling of imaging studies

Objective: 1. To assure proper patient preparation for imaging studies in order to avoid unproductive studies. 2. To ensure the greatest possible utilization of imaging equipment (particularly for exceptionally costly or scarce equipment). 3. To ensure most efficient sequence of studies. 4. To minimize patient and personnel waiting time.

Suggested Policy: 1. All studies requiring preparation or utilization of specialized equipment shall be scheduled in advance, and instructions concerning proper preparation, if any, shall be given to the patient.

Comment: It is usually not necessary to schedule conventional studies that may be performed in any of several rooms. In scheduling for specialized equipment, some time should be allowed for emergency examinations, preventive maintenance, and repair "downtime" of equipment.

Suggested Policy: 2. Algorithms shall be developed by the professional staff in conjunction with appropriate referring physicians to establish the most effective sequence in which to perform related studies, *i.e.,* urogram, barium enema, "upper GI." When groups of studies are requested, they shall be scheduled in accordance with these established sequences.

Control: 1. Periodic audit of "room logs" provides evidence of equipment utilization. 2. When studies are canceled and rescheduled because of improper sequencing or inadequate directions concerning preparation, a report should be filed in the department. Periodic review of these reports or order sheets will provide an indication of the frequency and source of such errors.

EXAMPLE C

Procedure: Patient reception

Objective: 1. To record essential patient demographic information. 2. To initiate the train of events necessary to provide requested

consultation. 3. To orient and reassure the patient. 4. To inform patient about procedure.

Suggested Policy: 1. On arrival, the patient should be greeted and the nature of the requested study reviewed. A file shall be created or updated to provide a permanent record of the visit, and demographic information shall be elicited and recorded. Specifically, the time of patient arrival shall be recorded. 2. The patient should be informed about the procedure by either the technologist or the imaging physician.

Comment: 1. Of utmost importance, at the patient's first contact with the facility, is the rapport established by the receptionist. Moreover, the data collected and recorded by the receptionist are essential to the proper functioning of all other segments of the facility.

Control: 1. Untoward events should be recorded in incident reports, the periodic review of which gives some index of the frequency of such occurrences. 2. A method for checking the functioning of the reception area is to provide regularly, or at least periodically, questionnaires designed to elicit patient satisfaction or dissatisfaction with various aspects of facility operation, or, alternatively, phone surveys after the visit may provide useful information.

EXAMPLE D

Procedure: Requesting the imaging study

Objective: 1. To ensure that a study is appropriate to the clinical problem with respect to the part examined and the projections recorded. 2. To assure that only essential studies are performed.

Suggested Policy: 1. Ideally, the imaging physician should review the history, interview and examine the patient, if indicated, and order specific projections. In practice, this role may be delegated to a resident physician or a technologist, but the technologist should be specifically trained for this task. 2. In the absence of a history, the imaging physician shall attempt to elicit one by calling the referring physician or by talking to the patient.

Comment: 1. For some studies standard views may be established, while in other examinations, it may be appropriate to tailor the examination to the clinical history—even for simple examinations such as skull or spine, choosing the appropriate views on the basis of clinical information may be warranted. In more complex examinations or some requiring greater radiation or other risk, the examination should be tailored to the clinical problem. 2. Successful control depends on having an adequate clinical history available.

Control: 1. Retrospective or prospective reviews of requests for imaging studies shall be conducted periodically, noting the percentage of studies with appropriate written requests versus the percentage without.

EXAMPLE E

Procedure: Wearing of gown

Objective: 1. To avoid artifactual images produced by clothing and jewelry on diagnostic images. 2. To ensure patient privacy and security of possessions.

Suggested Policy: 1. All patients needing studies of the chest, abdomen, thoracic or lumbar spine, pelvis, femora, or humeri shall wear a gown for the examination. However, infants should be radiographed without gowns if possible, and, if the pelvic region is radiographed, without diapers. Patients shall be instructed to remove any clothing or object in the area to be radiographed. 2. The patient's privacy and security for belongings shall be protected by providing a private dressing booth and a secure enclosure (dressing booth or locker) for belongings.

Control: 1. Periodic review of room logs or order sheets (requests) will show frequency of repeat studies occasioned by artifacts obscuring critical details. 2. Review of patient questionnaires will reveal causes of patient dissatisfaction, if any, with this procedure, which can lead to modifications if indicated.

EXAMPLE F

Procedure: Special nursing care

Objective: 1. To provide for the nursing needs of patients.

Note: This concern applies principally to hospital patients, but occasionally the condition of outpatients may require prompt action by facility personnel.

Suggested Policy: 1. Appropriate personnel shall be instructed and shall demonstrate competence in the use of oxygen tanks, suction devices, etc., and in servicing of hyperalimentation pumps, intravenous fluid systems, etc., as well as in assisting staff physicians in the management of reactions to intravascular contrast media and other pharmaceuticals. 2. Oxygen, suction apparatus, intravenous fluids, sphygmomanometer, and drugs necessary for the treatment of reactions to contrast media shall be readily available throughout the facility and shall be checked daily. 3. The expiration date on sterile equipment or drug products must be checked on a regular basis and

expired items replaced. Bed pans, urinals, etc., shall be available, and all personnel shall attend to patients' needs when requested. 5. Young children and very ill or disoriented patients shall not be left unattended in an examining room at any time, and stretcher patients shall be kept under constant surveillance.

Comment: 1. It is most helpful to store all of the necessities for treating an acute emergency in a "crash cart," with one individual assigned to be certain each morning that the cart is fully equipped and all devices are in working order. 2. If the number of acutely ill patients is large, it is well to employ a nurse or a licensed practical nurse to attend to nursing needs so that technologists are not diverted from their primary function. In some cases, it is best to require nursing personnel to accompany extremely ill patients.

Control: 1. Every untoward event involving a patient should be documented with an incident report. 2. Periodic review of incident reports will provide information concerning the frequency of acute nursing problems and will indicate any deficiencies in staff response.

EXAMPLE G

Procedure: Patient identification

Objective: 1. To preclude performing an examination on the wrong patient. 2. To avoid unproductive patient irradiation.

Comment: 1. Examination of the wrong patient subjects that patient to unnecessary irradiation and is a waste of time and film. This is a problem with children, the elderly, the hard-of-hearing, or the frightened patient who often responds to the wrong name.

Suggested Policy: The identity of every patient shall be established beyond doubt by the technologist before the radiographs are exposed.

Comment: 1. In the hospital setting, identification bands should be checked. In the case of outpatients, a repeated oral check of the patient's identity usually suffices. If the patient does not appear reliable, check personal papers, Blue Shield card or Medicare card, etc. 2. Technologists should determine that the description on the request form fits the patient.

Control: 1. File incident reports on all cases of mistaken identity and note the frequency of such occurrences as part of the periodic review of incident reports.

EXAMPLE H

Procedure: Radiograph identification

Objective: To ensure that the radiograph is identified with the proper patient.

Suggested Policy: The identification of radiographs should be done at the time of the examination or immediately thereafter.

Comment: Marking films in batches frequently causes errors and this practice should be avoided. Particular care must be taken in mobile examination procedures.

EXAMPLE I

Procedure: Patient positioning for an imaging study

Objective: To ensure that the radiographs record the requested anatomy in the requested projection.

Comment: Poor positioning may exclude critical anatomic detail from the radiograph or, by projecting it in a nonstandard way, may make interpretations uncertain and comparison with previous radiographs difficult. This is one of the most common reasons for repeating a radiograph. Poor positioning, therefore, often results in unnecessary patient irradiation, and, in some instances, improper diagnosis.

Suggested Policy: 1. A list of standard projections shall be made available to all technologists, and all technologists shall follow these directions rigorously. 2. Imaging physicians, in writing orders for studies, shall specify precisely what projection is required—PA, AP, RPO, etc.—and shall state explicitly desired degrees of obliquity or angulation. 3. Positioning aids (angle boards, etc.) shall be available to all technologists.

Control: 1. Periodically review room logs to determine the number of studies repeated because of poor positioning relative to the total number of studies done during the period being reviewed.

EXAMPLE J

Procedure: Patient immobilization

Objective: To prevent degradation of spatial resolution by patient motion during a radiographic exposure.

Suggested Policy: 1. The facility shall provide appropriate immobilization devices (foam bolsters, balsa wood blocks, sandbags, immobilization boards, velcro straps, etc.) for every radiographic room in which they may be needed, and technologists will employ them in positioning patients to eliminate motion during exposure. 2. In the rare cases when it is necessary for someone to hold a patient for

positioning and immobilization appropriate radiation protective clothing (apron, gloves) shall be provided.

Comment: 1. One of the most effective measures to eliminate respiratory motion is for the technologist to have the patient practice breath holding. This is not necessary for most patients but should be encouraged in children and in the case of "difficult patients." 2. Use of immobilization devices is particularly important in the examination of infants and small children.

Control: 1. Periodically review room logs to determine number of retakes due to patient motion.

EXAMPLE K

Procedure: Selection of exposure factors

Objective: To ensure that the density and contrast of the radiograph are consistent with accurate diagnosis.

Comment: Overexposure and underexposure are the principal reasons for repeating radiographs. These errors increase costs and increase patient irradiation. Precise control of exposure factor selection is the most important optimal performance goal in an imaging facility.

Suggested Policy: A. In situations without phototiming:
1. A technique chart shall be posted over the control panel in each examining room listing factors to be used for patients of various sizes for all studies that might be done. Once posted, this chart can be changed only with the approval of the chief of the facility or the chief technologist; 2. Technologists must measure each body part being imaged; 3. Technologists shall follow precisely the technique chart for the room in which they are working; 4. To alter the standard technique ("underexposed" radiography for soft tissue detail, for example), the imaging physician shall explicitly order an underexposed (or overexposed) radiograph and the technique desired; 5. In exceptional cases, the chief technologist or supervisor only shall also be authorized to modify established technique factors.

B. In situations where phototiming is available—The same policies as for non-phototiming should be in force in addition to the following:
1. A list of situations when phototiming is and is not to be used should be posted. 2. kVp settings with phototiming as well as levels of density for various examinations should be posted.

Comment: 1. Patient positioning and choice of proper detector are critical when phototiming is used. 2. Care must be taken that the detector is not over the area of the gonadal shield.

Control: Periodically review room logs to determine number of retakes due to overexposure or underexposure of the radiograph.

EXAMPLE L

Procedure: To avoid mismatching films and screens, an error that may result in significant over- or underexposure of images and repeat studies.

Suggested Policy: 1. Mechanisms must be developed that eliminate mismatching the cassette and film. The simplest approach is to use only one type of film and cassette in any darkroom. 2. An alternative if handling more than one speed system in a darkroom, is to use only certain sizes of cassettes with certain types of films. For example, use of the fastest screen-film combination for evaluation of scoliosis with only 14×36-inch cassettes and films.

Comment: 1. This is difficult in facilities with centralized film processing. It is feasible for dispersed processing in multiple small darkrooms and eliminates one significant source of exposure error.

Control: Periodically review room logs to determine number of retakes due to mismatching of films and screens.

EXAMPLE M

Procedure: Determination of adequacy of study

Objective: 1. To ensure that no patient is released until a study adequate for diagnosis is obtained. 2. To be certain that images are attributed to the correct patient and that time and position markers are accurate and correctly placed.

Comment: An inadequate study is a waste of time and money and exposes the patient to needless irradiation, and may result in an incorrect diagnosis.

Suggested Policy: 1. Radiographs should be reviewed as soon as processed so that defective radiographs can be repeated without unduly delaying the patient. 2. No patient should leave the facility until the radiographs have been reviewed unless the inpatient can be returned to the facility or the outpatient understands that it may be necessary to return for additional radiographs. 3. The physician responsible for the imaging shall be certain that the identification of the radiograph agrees with the request form and that the area of concern can be compared with previous radiographs of the same individual.

Comment: In many facilities, this task is assigned to a technologist; this is not an ideal practice. It is far better if the imaging physician

reviews the radiographs at this point, for several reasons: 1. If the imaging physician who is able to judge whether an image, even though defective, suffices for the diagnostic problem at hand performs this review, repetition of defective, but diagnostically adequate films can be avoided; 2. In many cases, supplemental projections (oblique, apical lordotic, tangential, etc.) may be needed to clarify the findings in a survey study. Only the imaging physician can recognize this need, and if the decision is made promptly, the supplemental images can be obtained during a single patient visit; 3. In many cases, the referring physician will have requested a "stat" interpretation. In these cases, the imaging physician will have to review the images immediately, and it is more efficient to check their quality while interpreting them than to wait for a technologist to check; 4. Technical errors identified by the imaging physician can be reviewed with the responsible technologist immediately, which is much more effective training than a review after a lapse of time; 5. To make this system work with maximum efficiency, previous radiographs must be available immediately for comparison.

EXAMPLE N

Procedure: Patient release

Objective: To be certain that the patient remains available long enough to permit additional radiographs to be made if needed and detain the patient no longer than necessary.

Suggested Policy: 1. Explicit notification shall be given to the technologist or receptionist directing release of the patient. 2. The time of patient release shall be recorded.

Comment: The time interval between patient arrival and patient release is a critical measure of the efficiency of the imaging service. These data should be reviewed periodically.

EXAMPLE O

Procedure: Interpretation of radiographs

Objective: To assess accurately the clinical status of the patient and diagnose accurately any disease process.

Comment: This is the primary objective of the entire image facility. It is the most important aspect of the facility operation.

Suggested Policy: 1. Radiographs shall be interpreted as promptly as possible in accordance with generally accepted standards of professional imaging practice, including review of pertinent previous images

and consultation with the referring physician. 2. There shall be a written report of every imaging study produced in the facility.

Control: Pathology and surgery reports on patients who have had imaging studies done should be sent to the imaging facility and, when appropriate, these should be compared with the interpretations of imaging studies. Cases in which the interpretation of an imaging study was proved inaccurate by other types of investigation should be reviewed at a regularly scheduled conference of the staff imaging physicians.

Comment: This is one of the most important and educational aspects of a quality assurance program. The comparison of imaging reports with reports of other studies should be performed by a physician. Such comparison should be done by an imaging physician. It is an excellent teaching exercise for residents. In the absence of resident physicians, the imaging physicians should share this responsibility.

EXAMPLE P

Procedure: Report generation and distribution

Objective: 1. To generate "hard copy" reports of the imaging physician's interpretations of diagnostic imaging studies. 2. To deliver or send signed copies of such "hard copy" reports to the appropriate sites (physicians' offices, patients' hospital charts, hospital record room, etc.) as promptly as possible after completion of the imaging study.

Suggested Policy: 1. Interpretations of all imaging studies shall be dictated (or otherwise generated) by the imaging physician as soon as possible after the completion of the study. 2. Dictated reports shall be typed immediately or transcribed as promptly as possible. 3. Imaging physician shall verify and sign reports promptly. 4. Reports shall be delivered or mailed as soon as they are signed. 5. The time at which the completed report is dispatched from the facility and the method of delivery should be recorded.

Comment: 1. The operation of this aspect of the imaging facility function is variable, and the same policies may not apply in all facilities. The intent is to perform each of the several steps in report preparation as quickly as possible after the completion of the previous step. 2. A major problem in this aspect of facility function is the tendency to "batch" the records, which defeats the objective of prompt report distribution. It is much more effective to collect dictation several times a day than to hold an entire day's dictation before giving it to the typist. 3. An even more rapid approach is direct dictation by the imaging physician to a transcriptionist. 4. Physician

delay in signing reports is a notorious source of delay. 5. Computer reporting systems are available, which expedite the generation of, at least, normal reports. However, most such systems have not found wide acceptance, and most facilities find conventional report generation satisfactory if personnel at all levels are constantly reminded of the importance of the prompt completion and distribution of reports.

Control: 1. Periodic review of patient logs, noting the interval between patient arrival and report distribution, is a useful measure of the overall efficiency of the report-generating system. 2. A useful way of analyzing the data is to note what fraction of the reports were dispatched within 4, 8, 12 hours, etc. If the time for report generation is excessive, individual aspects of the operation should be separately reviewed to identify the source(s) of the problem.

EXAMPLE Q

Procedure: Radiograph and report filing and retrieval

Objective: 1. To be certain that imaging studies and their interpretations are available without undue delay to assist clinicians in patient management. 2. To be certain that previous images, if such exist in the facility, are available to the imaging physician interpreting any new images to assist in that interpretation. 3. To be certain that imaging studies are made available for educational purposes, *e.g.*, teaching conferences, and for research projects. 4. To be certain that imaging studies, reports, and other records are available for quality assurance review, medicolegal, and other nonpatient care purposes as required.

Suggested Policy: 1. All imaging studies shall be filed in accordance with an established system (alphabetic, numeric, terminal digit, etc.) in an accessible location and shall be retained for as long a time as space permits or local ordinances may require. 2. All studies removed from the file shall be signed out by the responsible physician or other authorized person and a record of the transaction shall be kept until the study is returned. 3. No study shall be removed from the department until at least a provisional interpretation has been rendered. 4. If images are removed from the department, it should be for a limited time period, and mechanisms of retrieval should be available. 5. Copies of all reports and other pertinent records shall be filed with images or in a separately maintained record file, and, ideally, duplicate reports should be filed—one with the study and one in a separate file or in a hospital patient record, so that the record is complete even if the radiograph envelope is removed or lost.

Comment: Control of the image file room is the most difficult aspect

of departmental operation and record keeping is an important departmental function. In general, the more efficient the file room, the fewer radiographs will be removed without authorization by the referring staff. It is an aspect of facility operation that deserves the closest of supervision. One approach to decreasing the removal of radiographs from the department is to have an area within the department where images can be displayed. A number of devices are now available to facilitate efficient operation, *e.g.*, color-coded envelopes to prevent misfiling, computer systems to track images by scanning bar codes with a light pen, etc. Efficient operation still depends primarily on the care and interest of the file room personnel.

Control: A number of review procedures for file room functions have been suggested: 1. A count of the fraction of envelopes misfiled; 2. A count of the fraction of envelopes that cannot be retrieved in a reasonable time; 3. A study of the average time required to retrieve a record, etc. Unfortunately, it is difficult to conduct such procedures without adding to the burden of the file room staff, and such studies may, therefore, be counterproductive. It is, for this reason, better to review file room operation by studying its response to a request for a few randomly selected cases every day than to conduct large periodic studies.

6. Photographic Quality Control

In most of the modalities discussed in this report, film is used and the final link in the diagnostic imaging chain, photographic processing, is very important and often the one that is overlooked. All of the efforts by the technical staff aimed at maintaining quality imaging equipment will be futile, if the photographic processor is not maintained under a good quality control program.

The photographic process controls not only the image quality (*e.g.*, contrast, density, base-plus-fog) but also the patient exposure. A study of 409 processors in 256 facilities in New Jersey (Suleiman *et al.*, 1982) found that the radiographic film speed varied in excess of a four-fold range as a result of photographic processor variation alone. In addition, the base-plus-fog ranged from 0.13 to 0.55 for the films being used in the various facilities.

This section deals not only with the photographic processor and all of the associated aspects of film processing including darkroom fog, daylight loading systems, darkroom conditions, film and chemical storage, but also with daily processor quality control.

6.1 Storage, Darkroom, and Processing Conditions

6.1.1 *Film and Chemical Storage*

Photographic film is a *photosensitive* material but it is also sensitive to heat, humidity, chemical contamination, mechanical stress, and ambient radiation. Photographic materials should be stored at temperatures less than 24°C (75°F) preferably in the range of 15 to 21°C (60 to 70°F). Open packages of photographic film should be stored in an area with humidity ranging between 40 and 60 percent. Photographic materials should not be stored in areas where they can be exposed to chemical fumes or radiation. Sources of ionizing radiation include radioisotopes, radioactive wastes, and direct or scattered x rays. Photosensitive materials are also sensitive to pressure damage; consequently, film should never be stored except standing on

edge. Even two or three boxes stacked horizontally can cause pressure artifacts.

Photographic chemicals should receive reasonable care in terms of storage conditions. Never allow liquid photographic chemicals to freeze. If chemicals are frozen, and there is any evidence of sedimentation in the container, the chemicals should not be used and should be returned to the vendor.

6.1.1.1 *In the Vendor's Warehouse.* Film accounts for a significant portion of a facility's budget. It is difficult to monitor storage conditions in the vendor's warehouse, but a visit to the vendor's warehouse, especially in the summer, may be worthwhile. The following should be checked; storage temperature and humidity conditions; vertical storage of boxes of film; procedures to ensure that the oldest film and chemicals are sold first; film and chemicals not being allowed to sit on loading docks or in enclosed trucks for more than short periods of time (this is especially important in the south and southwest).

6.1.1.2 *In-House Storage.* Correct storage conditions should be verified in the facility's storage area. The emulsion batch that will expire first should be used first. Film should not be allowed to remain in the film bin past the expiration date. New shipments of film should be checked to ensure that emulsion batches are not accepted from the vendor unless they can be used before the expiration date. Control films should be processed periodically to ensure that film has not been exposed to chemical fumes or radiation.

A good quality control program must be sensitive to the problems of film and chemical storage and usage, and the storage conditions should be monitored at least monthly.

6.1.2 *Darkroom Conditions*

A major problem encountered in most darkrooms is dust and dirt. Darkrooms, where additional, meticulous cleaning is required, are often overlooked by custodial personnel. Smoking, eating, and drinking should be banned in all photographic darkrooms. Smoking produces ashes that can produce artifacts in cassettes, and smoke residue can be deposited on screens as well as on sensitive processor detectors. Smoking also produces light which fogs film. Eating also results in particles which can be deposited in cassettes and cause artifacts. When any beverage is spilled on a cassette, the screens will probably have to be replaced. If a beverage is spilled in the film bin, the cost of replacing the film may be great.

Care must be taken to ensure that chemical solutions are not spilled and allowed to dry, since the powder from this source will cause film artifacts and can contaminate other chemical solutions.

Darkrooms should be adequately illuminated, but the degree and wave length of illumination must be such that film fogging does not occur. Darkrooms should be painted white or with light colors, since this helps vision in situations where the degree of illumination is minimal. The counter tops should also be white, or light-colored, and a light-colored backing on the wall behind the film loading counter should be resistant to damage from cassettes and cassette covers during loading.

Other often overlooked aspects of the photographic darkroom are the appropriate temperature and humidity conditions. The temperature should be maintained at a comfortable level regardless of the number of individuals working in the darkroom. In addition, the humidity should be maintained between 40 and 60 percent. If the humidity is allowed to drop below 40 percent an increase in static marks on the film will usually result. If humidity rises above 60 percent, the films sometimes become sticky and film handling becomes difficult. High temperature and/or high humidity cause perspiration resulting in increased finger marks on the final radiographs. Low or high humidity cause difficult film transport for automatic cassette loaders and film handling systems in the darkroom and for rapid film changers.

Many x-ray facilities provide lead shielding on the walls to the seven-foot level. Care should be taken to ensure either that film is not stored above this level in darkrooms adjacent to exposure rooms or that the lead shielding is extended to the ceiling in such areas.

6.1.3 *Darkroom Fog*

At present, over 50 percent of all darkrooms used for medical imaging fog film (Suleiman *et al.*, 1982; Suleiman *et al.*, 1984). Film fogging must be eliminated, because it reduces film contrast in the mid-density regions (often the densities of most importance to imaging physicians), before its effect is visually apparent as an increase in density in the unexposed portion of the film. In addition, small amounts of fogging will increase the apparent speed of the film, but this speed increase will vary from sheet to sheet depending on the amount of fogging each sheet received.

Adequate time (15 to 20 minutes) should be spent in the darkroom before testing for darkroom fog to allow for dark adaptation and to allow visual inspection of the darkroom for visible white light. All

white light should be eliminated, and indicator lights on processors, timers, etc. should be checked to ensure that they don't cause film fogging.

The test for fogging should use the fastest film normally handled in the darkroom. If more than one type of film (*e.g.*,blue sensitive, green sensitive, double emulsion, single emulsion, etc.) is used, then the fastest film of each type should be tested. A *visible light* exposure should be made on the film with a step wedge or sensitometer so that a complete range of densities is obtained. ("Visible light" means exposure to any light source which results primarily in a light, not x-ray, exposure. It is appropriate to make a radiograph of an aluminum step wedge using a screen-film system.)

Exposure of test film for one minute in the darkroom with safelight on should produce less than a 0.05 increase in the mid-density portion of the film (*i.e.*, at a density of about 1.20). Ideally, less than a 0.05 increase should also be obtained with the two minute exposure to the darkroom lights. A more detailed discussion of the test for darkroom fog is available (Gray *et al.*, 1983).

Testing for fog by placing an unexposed sheet of film on the counter top in the darkroom and covering part of it with an opaque object will not properly indicate the fogging conditions (Gray, 1975). Since photographic materials have a threshold, the unexposed portion of the film will be less sensitive to fog than a portion already exposed.

Darkrooms should be checked for fog at least every six months, any time that fog or increased film speed may be suspected, any time light bulbs or filters are changed in the darkroom safelights, or any time maintenance is done on the processor or in the darkroom.

6.1.4 *Manual Processing*

Facilities at which the daily volumes of film are low or where films may be processed a few days a week should probably use manual film processing. Most small dental practices would probably obtain more consistent film quality at a lower cost with proper manual processing.

Processing time must be selected based on the temperature of the developer solution (manufacturers provide time-temperature charts for the particular film-developer combination being used). *"Sight" development should never be used to compensate for poor radiographic technique.* An accurate timer should be used for all processing, and the development time should be that specified by the manufacturer for the developer temperature being used. The accuracy of the timer and thermometer should be checked monthly. Solutions should be

replenished as recommended by the manufacturer, normally daily, based on the volume of films processed. When the chemicals are not in use, floating covers should be placed on the surface to prevent evaporation and chemical oxidation. Finally, quality control checks should be performed to ensure the activity level of the chemicals before processing clinical films.

6.1.5 *Minimum Number of Films for Automatic Processors*

When chemicals are formulated for mechanized film processing, the manufacturers assume that a certain number of films of various sizes and of typical radiographic density will be processed daily. The replenishment formulation and rates specified are designed to compensate for the chemicals exhausted by the development process as well as by oxidation, and to take account of the by-products of the development process which are left behind in the developer and fixer. If a minimum number of films is not processed, if the mix of sizes, or the average density are not what the manufacturer assumed, then an unstable processing situation results. Most mechanized processors and the chemistry available for them require a minimum (25 to 50) of 35 × 43-cm (14 × 17-inch) films (or an equivalent area) be processed every day to maintain the chemicals at the appropriate activity level. If this volume of film is not processed, or if the film density is lower than is usually seen in radiographs (*e.g.*, films used for radionuclide scans), then flood replenishment (see Section 6.3.1) or special chemistry may be the only way to maintain a stable processing system. If the volume, in terms of the total area of photosensitive surface is sufficient, but a limited number of film sizes is processed [*e.g.*, a dedicated processor in a mammography area processing mostly 20 × 25 cm (8 × 10-inch) film], then the replenishment rates may require adjustment to obtain a stable processing system.

6.2 Processor Quality Control

6.2.1 *Methods for Processor Quality Control*

The best means for processor quality control is to process a freshly exposed sensitometric strip and read that strip with a densitometer. Other methods for processor quality control have been proposed including the measurement of the developer specific gravity, bromide

concentration, and pH. Specific gravity does not provide an indication of developer activity but may be useful to ensure that new developer and replenisher solutions have been properly diluted and mixed. Both bromide concentration and pH have been shown to be of no value in processor quality control (Hall *et al.*, 1978; Stears *et al.*, 1979), because there are many chemical components in the developer solution, there are many complex chemical interactions between these components, and some components and their activity levels may or may not be affected by the pH of the solution.

6.2.2 *Aged vs. Fresh and the Type of Film for Sensitometric Strips*

The objective of processor quality control is to test the processor and chemicals with the same film (which has been exposed to a known, constant amount of light) normally used in the processor. There are four implications in this which must be understood.

(1) The medical imaging films being processed have been recently exposed, probably within minutes of processing. Consequently, the sensitometric strips should be freshly exposed to best mimic the clinical situation. This is particularly important since strips which have been previously exposed, especially those exposed days or weeks before, are less sensitive to changes in the developer solution activity (Poznanski and Smith, 1968).

(2) The sensitometric strips should be exposed to light, not directly to x rays, since x rays produce a different type of latent image which is also less sensitive to changes in the developer solution activity (Poznanski and Smith, 1968). (Note that films exposed with intensifying screens are exposed mainly with light and that the x-ray exposure has relatively little effect on the film.)

(3) Since the purpose is to eliminate as many variables as possible, it is necessary to use a sensitometer to expose the film so that a known, consistent exposure (within a few percent) can be applied to the film. Always keep in mind that the output of the sensitometer may vary with time. This may be difficult to determine unless a second sensitometer, one which is not frequently used, is available for comparison purposes. Goldman and Watkins (1978) found minimal variation during life testing of most sensitometers available at that time.

(4) The type of film used for the sensitometric strips should be the same as that normally processed in the photographic processor. It is not unusual to find that different types as well as different brands of film may respond differently to changes in developer activity. If more than one type of film is processed in a particular photographic

processor, it will be necessary to monitor that processor with each type of film, meaning that more than one sensitometric control strip will be needed.

It needs to be reemphasized that the control strips should be exposed with a sensitometer, and processed within two hours of exposure (ANSI, 1982; Gray *et al.*, 1983), and that the type of film used for the control strips should be the same as that normally processed in a particular machine, even if this means processing more than one control strip for each machine.

6.2.3 *Photographic Processor Control Charts, Operating Levels, and Control Limits*

Control charts are the key to the photographic quality control program, since they allow for the perception of trends, both slow and rapid changes, in the areas being monitored. For detailed discussions of control charts see Gray, 1977; Gray *et al.*, 1976; 1977; 1983; Western Electric, 1983.

Most processor quality control programs monitor three quantities: base-plus-fog density; mid-density (usually around 1.0 above the base-plus-fog level); a density difference (usually measured between 0.25 and 2.00 above the base-plus-fog level). These levels are based on the American National Standards Institute (ANSI) standard for measuring radiographic film speed and contrast (ANSI, 1981) and are also suitable for other applications, *e.g.*, nuclear medicine, those handling mostly films from hard-copy video cameras, or those processing mostly single emulsion or duplicating films. It has also been suggested that it is only necessary to monitor a mid-density level for a basic processor quality control program (Goldman *et al.*, 1977).

Since the photographic manufacturers do not provide standards, establishing the operating levels presents a problem but detailed guidance is available (Gray *et al.*, 1983). The upper and lower control limits can be readily set. For radiographic materials and films of similar contrast the upper control limit (UCL) and lower control limit (LCL) for the mid-density and density difference should be set at ± 0.10 (in density) and the UCL for the base-plus-fog level should be set at + 0.05. It has been suggested (Lawrence, 1973) that the control limits for the mid-density and the density difference should be broader (± 0.15), especially for the mid-density level. However, it may be worthwhile to set the limits at this broader range upon initiation of the processor control program and then decrease them to ± 0.10 after a month or two of experience. For lower contrast

films, such as cine films, the control limits can be set tighter, *e.g.*, ± 0.08.

Films vary in speed and contrast from batch to batch of emulsion. (The mid-density may vary by ± 0.10 or more.) Consequently, a quantity of the same emulsion batch of film sufficient to last at least one month should be isolated for quality control purposes. Before the last sheet of this emulsion batch is used it is necessary to do a "crossover" check to determine the change in the operating level for the control charts (Gray, 1977; Gray *et al.*, 1976; 1977; 1983).

The same operating levels and control limits should apply to all processors handling the same type of film throughout the department or institution. This ensures that if one processor is out of operation for any reason the films can be processed in other processors with the same results.

6.2.4 *Establishing and Maintaining a Processor Quality Control Program*

The establishment of a good processor quality control program requires that at least one motivated individual in the department be properly trained. That individual should primarily be responsible for exposing and processing the sensitometric strips, reading the strips on the densitometer, plotting data on the control charts, analyzing the results, and initiating corrective action.

Establishment and maintenance of a photographic processor quality control program requires attention to details. As an example, to minimize measurement variability the sensitometric strip should be processed so that the low density end leads the strip into the processor and the strip should be fed into the processor at the same location (left to right) on the feed tray each time, which ensures minimal retardation of development of the film by the flow of development by-products. Temperature and agitation in some processors may vary with the location (from left to right), so processing the strip in the same location each time eliminates this variable. For detailed discussions of photographic processor quality control programs, see Gray, 1977; Gray *et al.*, 1976; 1977; 1983.

Processor quality control should be carried out at the beginning of each day, after sufficient time has elapsed for the developer temperature to reach its operating level and stabilize. Also, any time that films appear to be consistently light or dark the processor should be checked, especially if films from two or more rooms are processed in the same processor and all appear to be changing.

In addition to processing and reading sensitometric strips each

morning, several other steps are required to ensure that the photographic processor is functioning properly. It is important to read and follow the manufacturer's instructions on weekly and monthly cleaning and preventive maintenance and to ensure that the recommendations are carried out. *Daily,* before processing any films, the level of the developer and fixer in the processor tanks should be checked and brought to the normal level with replenisher if needed. Unprocessed films, sometimes called clean-up films, should be processed before processing clinical films. Unprocessed films are used, as opposed to old processed film, since they swell more and clean the residue from surfaces inside the processor more effectively. In addition, these films tend to scratch more easily than do old processed films so that the clean-up films provide a check for processor scratching. After the processor clean-up films have been run and checked for scratches, the daily sensitometric strips may be processed.

At the end of the work day the cross-over rollers should be removed, cleaned with warm water and a damp, soft cloth, and dried. (The cross-over rollers should not be replaced in the processor until the processor is started the following day.) Any chemical deposits in the processor should be removed with a damp cloth. The cover of the processor should be left open about 5 cm (2 in.) so that moisture and chemical fumes do not accumulate and cause corrosion.

The simplest correction to make if the processor is above or below control limits, after checking developer temperature, is to change the chemicals. This takes a minimum amount of time and the cost of chemicals for most processors is relatively small.

6.2.5 *Evaluation of the Fixing Process*

The small number of photographic problems associated with fixer solutions would not be reduced significantly by extensive quality control efforts. Fixer solutions should be changed regularly, whenever developer solutions are changed, and the fixer tanks and racks should be cleaned at that time.

The color or appearance of the fixer provides no indication of the fixer solution composition. The pH or silver concentration could be monitored as an indicator of fixer activity, but this is not considered necessary. Fixer problems may be indicated if the films are not completely dry as they leave the processor, although there are other causes for this problem.

The amount of fixer replenisher added for each sheet of processed film should be that specified by the manufacturer. In addition, the amount of fixer added for each sheet of film processed should be

checked daily using the built-in flow meter, and the accuracy of the flow meter should be verified quarterly.

6.2.6 *Film Washing for Archival Quality*

Many valuable photographs, films, and radiographs have been rendered useless by the appearance of yellow or brown stains and fading as a result of insufficient washing. Without adequate washing, which is intended to remove the residual fixer, staining may occur in five years or less. However, for archival purposes, staining should be prevented for at least 10 and preferably 20 to 25 years. In order to ensure this, films must be adequately washed and should be stored under the appropriate conditions of temperature [21°C (70°F)] and humidity (40 to 60 percent) in envelopes which are designed for archival storage, *e.g.*, the paper is not acidic (Thomas, 1973; ANSI, 1984).

Tests for fixer retention are described by Thomas (Thomas, 1973) and several manufacturers offer kits to test for retained fixer. Most kits require that a few drops of a test solution be applied to one emulsion (of dual emulsion films) and that the resulting stain be compared to a standard sample. Ideally, for archival storage, less than 2 $\mu g/cm^2$ thiosulfate ion (fixer) should remain in the film after washing. Tests for retained fixer should be carried out at least every six months or, preferably, every three months.

Another useful tool in ensuring adequate film washing is a flow meter on the water line feeding the processor. This should be inspected daily to ensure adequate flow, especially if water filters are required to remove particulate matter from the water before it enters the processor. (The water flow rate required for each processor is stated in the manufacturer's specifications.)

6.2.7 *Processor Transport Time, Solutions and Wash Water Temperature*

Most mechanized processors have fixed transport speeds, or times, but it is possible to make minor adjustments in these speeds internally. However, minor changes can significantly affect the developed film since the total developer immersion time (the time the film actually spends in the developer) is on the order of 20 seconds for a 90-second processor. Most processors are stable enough so that it is not necessary to monitor the processor transport time on a regular basis.

The processor transport time is measured, using a stop watch, from the instant that the leading edge of the film enters the entrance rollers until the leading edge exits the last set of rollers in the drier section of the processor.

Slight changes in developer temperature can significantly affect the final image. Consequently, the developer temperature should be that recommended by the manufacturer for the specific film-developer combination being used and should be maintained within ± 0.3°C (± 0.5°F). The fixer temperature is not as critical but should be maintained within ±3°C (±5°F) of the developer temperature. The wash water temperature depends on the type of developer being used and the model of processor. Some systems require that the wash water temperature be controlled at approximately 3°C (5°F) less than the developer while many, newer processors (with the appropriate chemistry) operate with cold water only [but the cold water must be at least 3°C (5°F) less than the temperature of the developer].

Thermometers which use mercury in a glass tube should never be used around photographic processors. Mercury is a photographic sensitizer (at the level of a few parts per million) and would be virtually impossible to remove completely if a thermometer were broken in the processor or darkroom. Dial thermometers with long stems and reasonably priced digital thermometers are available.

There may be slight variation in the temperature of the developer or fixer solutions depending on where the temperature is measured in the tank. One point should be selected, which represents the average, and only that point should be monitored thereafter.

A built-in thermometer should be available in every processor to check the operating temperature. The calibration of this thermometer should be checked periodically. In addition, an in-line thermometer should be available to monitor the wash-water temperature especially where temperature-controlled water is required for the processor or where wash-water temperatures may approach the developer temperatures in cold water processors (*e.g.*, in the south and southwest).

Processor transport time should be checked when installed and once every year thereafter. Developer temperature can be monitored daily with a built-in thermometer but it is not necessary to record the temperature unless a problem is detected with the sensitometric strips. It is important to remember that the sensitometric strip takes into account all of the processor variables including developer activity level, temperature, and processor transport speed.

6.2.8 *Water and Processor Filters, and Replenishment and Wash Water Flow Meters*

It is usually necessary to install water filters in the wash-water supply line to prevent build-up of particulates in the wash-water tank and the imbedding of this material in the emulsion of the film. These filters should not allow particles larger than 25 μm to pass. If it is found that the filter must be changed frequently, it may be necessary to install a second filter to remove the larger particles. It is also essential to install a flow meter to ensure that the proper flow of water is provided for temperature control and proper washing of the film.

Every processor should also contain a filter in the developer recirculation system. If the flow through this filter is restricted, the recirculation of the developer will be reduced resulting in sub-optimal processing. This filter should be changed at the regular interval recommended by the processor manufacturer.

A water-flow meter should be provided at the point where the water enters the processor. (For temperature-controlled wash-water systems the flow meter should be located between the water temperature control valve and the processor.) Water is used both to control the processor chemical temperature and to remove residual fixer from the film. Consequently, adequate flow, at the appropriate temperature, must be provided. The flow rate should be checked daily as part of the processor quality control program. (This is especially critical when water filters are used.)

For effective processor quality control it is essential that the proper amount of developer and fixer replenisher be added for each film processed. The replenishment flow meters should be calibrated when the processor is installed and the calibration should be checked quarterly. The meters should be checked daily to ensure that the appropriate amount of replenisher is being added for a fixed film size.

6.3 Special Systems

6.3.1 *Flood Replenishment*

For processor volumes less than 25 to 50 14- × 17-inch (35-X 43-cm) films per day, assuming an 8-hour processor operating day or in processors used for other than normal density radiographs (*e.g.*, films used for radionuclide scans), it may not be possible to control ade-

quately the concentrations of the chemicals. This may also be true even for processors which automatically shift into "stand-by" mode. In this case flood replenishment can provide stable chemical concentrations for optimal processing (Titus, 1979a; 1979b; 1979c; Frank *et al.*, 1980; Gray *et al.*, 1983).

Flood replenishment requires the modification of a processor so that it automatically adds a predetermined amount of modified replenisher at fixed time intervals. (The developer replenisher is modified by adding starter solution to the replenisher tank.) The amount and frequency of replenishment is selected so that all of the developer in the processor developer tank is replaced every 16 working hours.

6.3.2 *Daylight Systems*

Quality control of daylight loading systems starts with the proper design of the loading and processing area *before* installation. It is essential to ensure that the temperature and humidity limits specified by the daylight loading system manufacturer are not exceeded. High humidity will result in films sticking together causing jams. Low humidity will increase the number of static marks on film and also cause jams.

Preventive maintenance is the major tool of quality control for daylight systems. Routine inspections should be scheduled (at a frequency recommended by the manufacturer) and should cover the items noted in the manufacturer's maintenance manuals.

During system use the technologists should look for, and report, light leaks, film artifacts, improper loading of cassettes, improper unloading of cassettes, and the accuracy of the time and date portions of the automatic identification systems.

Each cassette, loader, and unloader should be permanently identified. A record keeping system should be developed so the technologist can record any equipment malfunctions, which will assist in the quick identification of intermittent or unusual problems. Also, a policy should be established whereby cassettes are always left loaded to reduce the possible double loading of cassettes.

6.3.3 *Silver Recovery*

Silver recovery should be a part of any well-managed diagnostic imaging department and may be required to meet environmental protection regulations. The quality control program must also mon-

itor the silver recovery equipment to ensure that all available silver is removed from the fixer and to ensure security of the silver prior to shipment to a refiner.

There are several methods, *e.g.*, silver test papers and direct reading devices, to measure the silver content of the fixer solution before the silver is removed. However, none of these methods is sensitive enough to measure the residual silver after silver recovery from the fixer solution. Consequently, it will be necessary to have the silver content of the effluent measured periodically to ensure that all of the available silver is being removed. Many hospital laboratories have this measurement capability and, even though it may be costly, the value of the silver lost from an improperly adjusted or nonfunctioning silver recovery system can be far greater. Hospital laboratories may have difficulty determining the amount of silver present after reclaiming, if fresh calibration solutions diluted with fixer are not used in the calibration process.

Assays of the silver content before and after silver reclamation should be done after every six batches, or at a minimum every 3 months. Records should be maintained to determine that the amount of silver available for resale is the same as that indicated by the assays. The silver should be stored in a secure location.

6.3.4 *Processor Stand-by Units*

These units are valuable, especially in lower volume facilities. When films are not being processed frequently, the stand-by unit places the processor in the stand-by mode, which usually turns off the drive system and reduces the water flow rate while maintaining the chemicals and film dryer at the correct temperatures. This reduces power and water consumption, chemical oxidation, and should increase the life of the processor by reducing the mechanical wear.

The scheduled preventive maintenance checks recommended by the manufacturer should be carried out. To ensure that the unit is operating properly, process a sheet of film and then measure the time before the processor goes into the stand-by mode. Also, it is important to ensure that the stand-by system cycles the processor on and off, and that the solution and dryer temperatures are maintained during stand-by operation.

6.3.5 *Automatic Chemical Mix Systems*

Automatic chemical mix systems may be a convenience in many departments but they are not useful for low volume facilities. Most

auto mixers mix a relatively large volume which oxidizes before the chemicals can be used in low volume facility. Auto mix systems, though convenient from the mixing point of view, are harder to clean and maintain than replenishment tanks.

In addition to the procedures recommended by the manufacturer, particular care must be paid to the knife or puncture blade supplied with the system. It must be clean, not deformed, and sharp. For most units the simplest maintenance for defective puncture blades is to replace them.

These systems will provide satisfactory mixing if they are maintained as recommended by the manufacturer. Specific maintenance and quality control procedures, as well as their frequency, vary among types so it is important to use the manufacturer's manuals for assistance in establishing a quality control program for automatic chemical mix systems.

6.3.6 *Systems Cleaner and Processor "Seasoning"*

Systems cleaners are special cleaning solutions designed to remove chemical residues from processor surfaces. Specific cleaners are available for developer and fixer tanks and should *never* be mixed or used for the inappropriate tanks. In addition, *some* manufacturers indicate that these cleaners may be used for tanks and recirculating systems but should never be used for processing racks, which are made of composite material and can absorb the cleaner. The processor manufacturer's manual should be checked for information concerning the suitability of systems cleaners for specific processors.

Since the developer systems cleaner is a highly acidic solution, and the developer is a basic solution, it is necessary to ensure that all of the systems cleaner is removed from the processor before refilling the tanks with fresh developer. This is done, by flushing the tanks with fresh water while running the recirculation system, and then, to eliminate any residual systems cleaner, by filling the tanks with developer solution diluted with an equal amount of water, and circulating this solution for 10 minutes. That process, known as "seasoning," is a good quality control procedure, since it minimizes the risk of contamination.

Note that even though it may be necessary to change the developer and fixer solutions every one to three months, systems cleaner should not be used regularly. Developer systems cleaner should only be used when necessary to remove silver and dirt buildup. Usually the buildup of silver and dirt in the fixer system is insignificant. Therefore the use of systems cleaner in the fixer tank is usually not necessary.

6.3.7 *Miscellaneous*

In addition to all of the above areas there are some "miscellaneous" items worth noting. The quality control technologist and others in the quality control program should always be alert to procedures that may result in film artifacts or degraded image quality. For example, the use of hand creams by individuals handling unexposed film will result in some of the hand cream being deposited on the film and transferred to the cassette, ultimately retarding development of the film, because the hand cream reduced the ability of the developer to penetrate the emulsion.

6.4 Film Copiers

Copy films are designed to reproduce densities faithfully from the original films up to a density of about 2.3 to 2.5. Consequently, copies should in most situations appear the same as the original film for most applications and the imaging physician should be scarcely able to distinguish the copy from the original, except for the shiny surface on some copy films. Note that since copy films are single emulsion films, they will never be able to reproduce all of the densities in original radiographs. They will be able to reproduce all densities which are visible on a radiograph in a conventional viewbox and should be able to reproduce faithfully the densities from single emulsion films.

Different types of bulbs are used in different film copiers. Most film manufacturers recommend the use of ultraviolet-emitting bulbs, sometimes referred to as BLB bulbs. In addition, some printers contain two or more light sources which can be selected by the position of a switch. It is essential to ensure that the correct bulb, or light source, is being used before attempting to optimize the film copying process daily or, if darkroom is not used daily, before each use.

Duplicating films are designed to copy radiographs and not to correct radiographs produced with incorrect density or contrast. Once the duplication process is optimized, good duplicate radiographs can be ensured by the appropriate quality control procedures. Ideally the film copier settings should not be changed for every duplicate radiograph produced. It is essential to readjust the settings to the "normal" position immediately after copying a poor quality original radiograph.

The emulsions of duplicating or copy films are relatively unstable

before processing. Consequently, only a few boxes of duplicating film should be stocked and that film should be used as quickly as possible.

Original films on the same type of film as those to be duplicated should be used for quality control tests. Different exposures may be required for films on different base materials, *e.g.,* clear vs. blue-based films, and sometimes even for the same type produced by different manufacturers.

Three or four original test films are needed to monitor the quality of the copy process: (1) a radiograph on dual emulsion film of an aluminum step wedge, resolution pattern, and an anatomical phantom such as a skull phantom; (2) a 14- × 17-inch (35- × 43-cm) radiograph of a fine mesh screen; (3) a film of the Society of Motion Picture and Television Engineers (SMPTE) test pattern and clinical images from a video hard copy camera (Gray *et al.,* 1985); (4) if possible a radionuclide scan film. The first film is used to set up the copy process and for routine quality control. The second film is used to ensure that adequate contact is maintained over the entire surface of the copier and that the duplicate and original films do not slip relative to each other if a roll-type copier is used. The film from a video hard copy camera should be copied and evaluated periodically if such films are duplicated. If radionuclide scan films are duplicated, an original radionuclide scan film should be available to ensure continued copy quality.

Once the appropriate operating levels have been achieved (Gray *et al.,* 1983) densities of the copy films should be measured with a densitometer, their contrast determined, and the data plotted on a control chart. (It is assumed that the processor is also monitored and within control limits.) The densities of the copy film which are monitored should be similar to those monitored as part of the processor or video hard copy camera quality control program. The control limits for copy film densities and contrast should be the same as those used in the photographic processor quality control program.

Copies of radiographs should be evaluated weekly or more frequently if many copies are produced. The contact between the copy and original film should be checked monthly using a radiograph of a fine mesh screen. If video hard copy camera or radionuclide scan films are duplicated, copies of the test originals of these films should be made and compared at least monthly, or more frequently where many copies are made.

7. Quality Control in Conventional Radiography

Conventional radiographic imaging systems have many elements, each of which is subject to variability or to change with time. To produce a single radiograph the kVp, mA, exposure time, beam filtration, focal spot size, grid (type, uniformity, and alignment), intensifying screens, cassettes, film, darkroom conditions, photographic processor and chemicals, to name the more important elements, must provide the appropriate function or the final film may not be clinically acceptable. Each element in the imaging chain can drift such that the image quality may be degraded. Consequently, to ensure optimum image quality with minimum radiation exposure to the patient and staff, and to do so in a cost effective manner, it is essential to measure and control all of the appropriate variables in the radiographic imaging chain.

Quality control tests for conventional radiographic equipment apply not only to conventional, stationary imaging systems, but they also apply to all imaging systems using a conventional x-ray tube and image forming chain. For example, most of the tests discussed in this section also apply to mammographic, conventional tomographic, mobile radiographic, dental radiographic, and special procedure (angiographic) imaging systems. In addition, some of these tests should also be used for digital imaging systems, whether direct digital imaging systems, such as digital chest systems, or systems designed for digital subtraction angiography (DSA).

7.1 X-Ray Tubes and Collimators

7.1.1 *Filtration*

Since it is not possible to measure the amount of inherent filtration in the x-ray beam, it is necessary to measure the half-value layer (HVL) of the beam. The HVL is the amount of aluminum required to reduce the exposure to one-half of its original value (at a fixed

TABLE 7.1—*Minimum half-value layers*
(FDA, 1986)

X-ray tube voltage (kVp)		Minimum HVL (mm of Al)	
Designed operating range	Measured operating potential	Dental systems	Other x-ray systems
Below 50	30	1.5	0.3
	40	1.5	0.4
	49	1.5	0.5
50 to 70	50	1.5	1.2
	60	1.5	1.3
	70	1.5	1.5
Above 70	71	2.1	2.1
	80	2.3	2.3
	90	2.5	2.5
	100	2.7	2.7
	110	3.0	3.0
	120	3.2	3.2
	130	3.5	3.5
	140	3.8	3.8
	150	4.1	4.1

kVp and mAs) and is *not* a measure of the amount of aluminum in the x-ray beam.

Under some conditions it is possible to increase the HVL which will decrease the exposure to the patient without significantly increasing tube loading. For example, for general radiographic applications to adults, increasing the HVL from 2.3 to 3.0 mm of aluminum (at 80 kVp) will reduce the patient exposure by 25 percent while not affecting tube loading or image contrast and minimally affecting radiographic density. Less significant changes in exposure will occur for pediatric patients due to the thinner body parts being imaged, and a slight decrease in contrast may be noted with increased x-ray tube filtration in pediatric radiography.

To measure the HVL it is necessary to have an accurate dosimeter and sheets of type 1100 aluminum, as well as semi-log graph paper. It is usually sufficient to evaluate the HVL at a single kVp, *e.g.*, 80 kVp for the typical diagnostic x-ray unit or higher clinical kVps for computerized tomographic systems. Minimum HVLs, as specified in federal regulations (FDA, 1986), are reproduced in Table 7.1.

It is difficult to specify an appropriate HVL for mammographic imaging with screen-film combinations, since these systems normally use a molybdenum target and molybdenum filter that produces an x-ray spectrum with a significant monochromatic component. However, for these systems a minimum HVL of 0.3 mm of aluminum at 30 kVp is required (FDA, 1986). (A range of 22 to 28 kVp should

be used for mammographic imaging with these systems.) For xeromammographic imaging the HVL should be at least 1.5 mm of aluminum at 45 kVp (NCRP, 1980; 1986). (A range of 40 to 55 kVp should be used for xeromammographic imaging systems.)

In addition to the minimum annual measurement of the HVL, the HVL should be measured when radiologic engineers replace an x-ray tube or perform any service on the x-ray tube or collimator. Replacement of the added filtration is easy to overlook, and the HVL measurement will quickly indicate this problem ensuring that the patients examined on the equipment are not needlessly exposed to lower energy radiation.

7.1.2 *Light Field, X-ray Field Alignment, Positive Beam Limitation (PBL) Accuracy, and X-Y Scale Accuracy*

The x-ray field must be aligned with the light field so that the technologist can accurately position the body part to be imaged. It is also important to ensure that the PBL (automatic collimation) system is setting the collimators so that the entire film area is being used and to ensure that the radiation field is not significantly larger than the film size. In addition the PBL system should allow collimation conveniently to a smaller field size from the full film size, when desired.

Problems with PBL systems depend on the age, complexity and usage. For example, the PBL system in a general radiographic room used strictly for adult radiography will present fewer problems than a PBL system in a room used for both adult and pediatric work. PBL systems are particularly troublesome in pediatric radiology where x-ray imaging fields smaller than the cassette are used. These require constant collimation to the smaller field size.

For those systems utilizing manual collimation it is necessary to evaluate the accuracy of the x-y scale indicators. This ensures that when a specific film size is selected the x-ray field will be collimated to the correct size.

There are several tools and techniques available for this test ranging from nine coins (AAPM, 1978) to special templates. These tools can be purchased from x-ray equipment vendors.

Federal regulations (FDA, 1986) allow ± 2 percent of the source-to-image distance (SID) in collimator light-to-x-ray field total misalignment along either the length or the width of the x-ray field. The center of the x-ray field must be aligned to the center of the image receptor to within ± 2 percent of the SID and the SID indicator must be accurate to within ± 2 percent.

For PBL systems, the length or width of the x-ray field may not differ by more than 3 percent of the SID compared to the image receptor dimension. The sum of the absolute values of the differences (x-ray field difference from image receptor size) for the length *and* width must not be greater than 4 percent of the SID.

For manual collimation systems, federal regulations (FDA, 1986) require that the x-y scale indicators be accurate to ± 2 percent of the source-to-image distance.

Inspection and verification should be performed every six months or whenever any service work involves the collimation system, collimator, or Bucky tray. It is important to inspect the PBL system with all cassette sizes used in the room and to ensure that it functions properly for each size cassette whether placed longitudinally or transversely. This can be done visually, *i.e.,* without making x-ray exposures or using x-ray film. Note that visual inspection of the light field on the table top will give a field smaller than the actual x-ray field in the film tray.

7.1.3 *X-ray Beam, Bucky Grid Motion and Centering, Image Receptor Alignment, X-ray Beam Perpendicularity, and Source-to-Image Distance Indicator Accuracy*

It is necessary to ensure that the x-ray beam is aligned to the cassette in the Bucky tray and that the Bucky grid is centered to the x-ray beam to obtain uniform density over the film. The motion of the grid is important since, if it is asymmetrical to the central ray of the x-ray beam, grid cut-off can result. In addition, the motion of the Bucky can introduce motion to the cassette which will result in motion blur over the entire radiograph.

The x-ray beam must be perpendicular to the grid to avoid grid cut-off especially with higher ratio, focused grids. Finally, the actual source-to-image distance (SID) must be the same as that indicated on the x-ray tube column or control panel.

A homogeneous phantom at least 30-cm square can be radiographed (with lead strips marking the center of the x-ray beam). The lead strips should be in the center of the radiographic image, and the film should be uniform within ± 0.10 in density from side-to-side, perpendicular to the anode-cathode axis.

Test tools are available to measure directly the x-ray central ray perpendicularity. The acceptance limits for the perpendicularity test are usually provided by the test tool manufacturer.

The accuracy of the source-to-image distance indicator is important in repeatedly obtaining the appropriate density of the film. This

distance must be verified using an accurate tape measure to determine the distance from the focal spot to the image receptor. The actual location of the focal spot in the tube housing must be known accurately and should be marked on the outside of the tube housing. The indicated source-to-image distance should be within ± 2 percent of the actual distance.

The above tests should be carried out any time that the film density appears non-uniform along a line perpendicular to the anode-cathode axis; any time service is performed on the x-ray tube or collimator; and at least annually.

7.1.4 *Focal Spot Size*

The size of the x-ray tube focal spot affects the final radiographic image quality. If the focal spot is too large, the quality of the image will be degraded. If it is too small, the exposure time will be increased to the point that patient motion may be a problem. Thus, it is important to select the appropriate focal spot size initially and to ensure that the measured focal spot meets the manufacturers specifications.

The National Electrical Manufacturer's Association (NEMA) provides a standard for measuring focal spots and for acceptable tolerances (NEMA, 1984). This standard requires the use of a slit camera for measuring focal spots. However, some manufacturers will still accept the star resolution pattern measurements in place of the slit camera measurements for the focal spot size.

NEMA provides specifications for the acceptance limits for x-ray tube focal spot sizes, measured under specified conditions, with specified techniques. These acceptance limits are provided in Table 7.2.

All x-ray tube focal spots should be measured as part of acceptance testing of a new radiographic system and each time an x-ray tube is replaced. For regular monitoring, however, it has been the experience of one group that the focal spot size measurement of over 200 x-ray tubes for eight years provided no worthwhile information about the condition of the tube.[3]

7.1.5 *Visual Checks*

Many inspections associated with the x-ray tube, collimator, and tube crane are simple visual inspections and should be performed as part of the quality control check. These may include accuracy of

[3]Personal communication from Joel Gray at Mayo Clinic.

TABLE 7.2—*Focal spot size acceptance limits* (NEMA, 1984)

Nominal size (mm)	Maximum focal spot dimensions	
	Width (mm)	Length (mm)
0.05	0.075	0.075
0.10	0.15	0.15
0.15	0.23	0.23
0.20	0.30	0.30
0.25	0.40	0.40
0.30	0.45	0.65
0.40	0.60	0.85
0.50	0.75	1.10
0.60	0.90	1.30
0.70	1.10	1.50
0.80	1.20	1.60
0.90	1.30	1.80
1.00	1.40	2.00
1.10	1.50	2.20
1.20	1.70	2.40
1.30	1.80	2.60
1.40	1.90	2.80
1.50	2.00	3.00
1.60	2.10	3.10
1.70	2.20	3.20
1.80	2.30	3.30
1.90	2.40	3.50
2.00	2.60	3.70

source-to-image distance indicator, accuracy and function and angulation indicator, function and effectiveness of table and all other locks, condition of high voltage and other cables, ease of overhead crane movement, stability and lack of vibration (after positioning and due to rotor starting) of the x-ray tube support and proper function of Bucky-cassette lock. A visual inspection can be extensive but can be performed quickly. (See Gray *et al.*, 1983 for an example of a visual check list.) These visual inspections should be made whenever service which might affect the tube, collimator, or tube crane is performed, and at least annually.

It is necessary for the collimator light to be bright enough to be seen by the technologist under reasonable room lighting conditions so that the patient may be positioned properly. This test should be carried out annually or after any service to the collimator assembly. Federal regulations (FDA, 1986) specify that the illuminance and contrast must be measured. A calibrated photometer is required to measure the illuminance.

7.1.6 *Mechanical and Electrical Safety Checks*

In addition to inspecting the tube crane locks it is important to inspect the condition of all cables and counterweights for overhead x-ray tube systems at least *annually,* and to lubricate them as indicated by the equipment manufacturer. This will require the assistance of a service engineer. Any support cables which show evidence of wear should be replaced immediately, for the safety of both patients and staff. For further discussion of mechanical and electrical safety checks the reader is referred to Section 21.2.

7.1.7 *X-ray Tube Heat Sensors*

Devices are available to monitor the amount of heat stored in the x-ray tube anode. Some of these devices monitor the temperature of the anode while others calculate the total heat units produced by the generator and the cooling as a function of time. While quality control checks are difficult to carry out on such equipment, a few items should be noted.

The x-ray tube heat sensor should be set to provide a warning when the anode heat reaches 75 percent of the maximum. When this level is reached, the system may either provide a warning or terminate exposures. Careful consideration should be given to the technique most appropriate to the situation.

Normally, the x-ray tube heat sensor monitors only the amount of heat in the anode, not in the x-ray tube housing. Most x-ray tube housings have thermal protection circuits but few provide an audible signal when the maximum housing temperature is being approached. Consequently, the technologist or physicist will have to calculate the heat input and determine the tube cooling to ensure that the housing heat limit is not exceeded in lengthy special procedures and in tomographic imaging studies.

Quality control technologists, as well as all other technologists, should be familiar with the four types of rating charts for x-ray tubes and housings including:

a) Single exposure rating charts (specific to focal spot size, anode rotation speed, single or three phase generators),
b) Anode thermal characteristic and fluoroscopic rating charts,
c) Housing cooling charts, and
d) Angiographic and cine rating charts.

With a thorough understanding of these charts it is possible to ensure

that x-ray tubes and housings are not overheated under normal working conditions.

7.1.8 *Off-focus Radiation*

It is usually assumed that x rays are generated from the focal spot of the x-ray tube. However, a significant amount of radiation may be produced from other surfaces in the x-ray tube. Off-focus radiation reduces image contrast especially in low scatter situations, *e.g.*, extremity and pediatric radiography, and, consequently, degrades image quality.

Off-focus radiation is difficult to measure but can be easily observed using the approach described by Thomas (Thomas *et al.*, 1983). Since off-focus radiation is difficult to quantitate, it may not be possible to incorporate this measurement into a quality control program. For further information on off-focus radiation the reader is referred to the literature (Weaver *et al.*, 1975; Rao, 1966; 1974).

7.2 X-Ray Generators

7.2.1 *Overload Protection*

Since x-ray tubes are expensive, it is desirable to ensure that excessive loads are not applied to the tubes and that the housings are not overheated by too many exposures in a short period of time, *e.g.*, in the angiographic suite. In addition, tube warm-up procedures should be followed to ensure that high loads, *e.g.*, lateral lumbar spine techniques, are not applied to a cold anode, because this could cause the anode to crack.

Overload protection is provided for a single x-ray exposure by most radiographic generators. It is important to check the overload protection against the single exposure rating chart to ensure that the generator will not allow an exposure in excess of that allowed for a specific x-ray tube. In most cases it is prudent to have the generator set to prevent exposures which exceed 80 percent of the single rating chart limits, but also, the overload protection circuit should not unnecessarily restrict techniques to much less than 80 percent, or the full potential of the tube and generator will not be available.

The overload protection circuit should be checked any time service is performed on the generator, and at least annually.

7.2.2 *Peak Generating Potential (kVp)*

The peak potential of the x-ray generator is probably one of the most important quantities to be measured, since it affects the quality of the x-ray beam, exposure of the patient, and contrast and density of the film. Drifts of as little as two or three kVp can significantly affect density, but greater changes are required to affect image contrast. In addition, improper calibration of the kVp, *e.g.*, obtaining 60 kVp when 70 kVp is desired, may result in patient exposures higher than necessary.

Peak generating potential can be measured with a modified Ardran and Crooks cassette to ± 3 kVp. With newer, noninvasive electronic kVp measurement devices the kVp can be measured with an accuracy of ± 2 percent and reproducibility of ± 0.5 kVp. The Ardran and Crooks cassette requires the exposure, processing and reading of densities on a film and the electronic devices provide an immediate measurement of the kVp. Even though the electronic systems may be more costly initially, the cost of the film required for the Ardran and Crooks cassette and the time required for processing and reading the densities should be considered in making a decision to purchase (Ardran and Crooks, 1968).

A noninvasive kVp measurement technique may differ from invasive measurements made by x-ray service engineers. Normally the invasive measurements indicate a slightly higher (2 to 5 kVp) peak generating potential than the noninvasive measurements. This is not a problem if the noninvasive measurement is used to verify consistency, as opposed to accuracy. In other words, once the x-ray generator is properly calibrated using invasive equipment, only noninvasive measurements need be made. If, for example, the noninvasive measurement is 77 kVp, when the properly calibrated generator is set at 80 kVp, 77 kVp becomes the operating level for the room quality control record.

The measurement of the peak generating potential and the acceptance limits present some potential problems. Most generators have kVp stations with a range of 40 to 150 kVp and mA stations with a range of 50 to 1,000 mA. Most manufacturers set fairly wide limits on the kVp accuracy (*e.g.*, ± 5 to 7 percent plus 2 kVp), since they are normally required to maintain the specified accuracy over the entire range of the generator. However, if the generator is going to be used in the normal diagnostic range, it is possible to obtain much better calibration over a limited range, *e.g.*, 60 to 100 kVp ± 2 kVp, than that specified by the equipment manufacturers.

The peak generating potential should be verified when the output

of the x-ray generator appears to have drifted, when any service is carried out on the generator, and at least annually.

7.2.3 *Exposure Timers*

The exposure time is an important quantity to measure, since it is one of the major factors that determines the film density. Change in the exposure timer accuracy is almost always independent of other factors such as kVp and mA unless there is a significant change in the x-ray output waveform.

Exposure times can be measured with several test tools. The simplest measurement device is a spinning top (only for single phase generators) or a motorized synchronous top (for both single and three phase generators). The next level of sophistication is an electronic timing device which records either the number of pulses (for single phase generators) or exposure time (for three phase systems). Finally, many modern digital dosimeters can measure not only radiation exposure but also, simultaneously, exposure time. Most of these commercial devices are dependent on the specific shape of the waveform.

Since the x-ray output waveform is not a perfect square pulse, it is necessary to define at what level, *i.e.,* percentage of peak radiation, the time measurement will be made. Many quality control programs measure the exposure time at 50 percent of peak since this correlates well with the exposure time measurements made with invasive methods utilizing 75 percent of the peak input voltage waveform. A few generators have characteristically atypical waveform shapes, *e.g.,* the waveforms may exhibit an initial pulse of low energy x rays (due to premagnetization) or long rise and fall times especially at low mA's (due to cable capacitance). However, it is necessary to look at the x-ray output waveforms using a detector and oscilloscope in order to determine this. (See Section 7.2.4 for details on monitoring x-ray output waveforms.)

All x-ray generators should be able to time exposures to ± 5 percent for times in excess of the minimum exposure time (for three phase generators). Single phase generators present a different problem, since the minimum pulse time is 8.3 milliseconds, and most systems cannot terminate the exposure during an x-ray pulse. Suggested control limits for single phase generators are given in Table 7.3.

Exposure time should be measured when any generator repair work is carried out by an x-ray service engineer, when problems have developed involving light or dark films, and at least annually.

TABLE 7.3—*Exposure time control limits for single phase full-wave rectified generators*

Exposure time (sec)	Acceptance limits
1/5	24 ± 1 dot
1/10	12 ± 1 dot
1/20	6 ± 0 dots
1/30	4 ± 0 dots

Note—when using a spinning top, the x-ray pulses are imaged as dots on the film as the small hole in the top is moved rapidly (rotated) over the film.

7.2.4 *X-Ray (Radiation) Output Waveforms*

Knowing that the exposure time is correct, the tube current is properly calibrated and the peak kilovoltage is correct may not tell the entire story concerning x-ray generator function. For example, invasive calibration of an x-ray generator measures the true *peak* of the voltage input waveform. This may be seen as a spike on the voltage waveform, excessive ripple in the voltage or tube current waveform, or as the waveform changing with time, information which would not be provided by typical kVp, mA and exposure time measurements. In each case the kVp, mA, and time may be correct, but the x-ray output will be different from that anticipated. In addition, the x-ray tube may be arcing or the generator may be producing rapid, transient spikes of exceedingly high kilovoltage—an indication of forthcoming tube and, possibly, cable and generator failure.

X-ray output waveform monitoring provides information regarding the functioning of the x-ray generator, *e.g.*, appropriate smoothing of the waveform, electrical arcing, etc. This is done by monitoring the output of the x-ray generation tube system with an x-ray sensitive detector (Gray *et al.*, 1983; Stears *et al.*, 1983). The detector may be a small solid-state detector, or an appropriate ionization chamber and electrometer. The output waveform may be displayed on a storage oscilloscope and photographed for future reference. A digitized waveform may be plotted using a computer-printer. (Normally only waveforms from acceptance testing need to be photographed and placed in the room quality control record.)

It is difficult to specify acceptance limits for x-ray output waveforms other than to say that the waveform should be nearly rectangular in shape and that three-phase waveforms should display a minimum amount of ripple. Any waveform that appears in any way to be abnormal should be photographed, all important exposure parameters should be recorded, and the waveform should be shown to the x-ray service engineer as soon as possible. Not only will this help the engineer to troubleshoot the problem, it may prevent costly equipment failure and damage.

The x-ray output waveforms should be monitored when waveform problems are suspected, and at least annually.

7.2.5 *Exposure per Unit of Tube Current and Time*

The four tests for the x-ray generator just described may show everything to be functioning normally, but there are other factors which may affect x-ray generator-tube output. It is difficult to measure accurately the x-ray tube current (mA) noninvasively. In addition, differences in anode configuration, condition, and system geometry can result in differences in generator-tube output. The purpose of the $\mu C\ kg^{-1}$ (mR)/mAs measurement is to determine if such problems exist.

The assessment technique requires measurement of the x-ray exposure at a fixed kVp and mAs, and under set geometrical conditions. This exposure in $\mu C\ kg^{-1}$ (mR) is then divided by the mAs to obtain the $\mu C\ kg^{-1}$/mAs. The exposure measurement may be made in air (without back-scatter) or may be made under a homogeneous phantom, or even in the Bucky tray. (The latter two methods come closest to approximating the measurement of radiation as seen by the screen-film system.) This ratio ($\mu C\ kg^{-1}$/mAs) can then be compared for various mA stations as an indication of mA calibration; for various x-ray units in order to standardize technique charts; or for similar x-ray units to determine differences in output.

The $\mu C\ kg^{-1}$/mAs should be maintained to within $\pm$ 10 percent (at 80 kVp) for rooms using the same types of x-ray generators, tubes, and tables. Under these conditions the same technique charts would be applicable. However, it may not be possible to obtain similar $\mu C\ kg^{-1}$ mAs with different types of equipment. If the $\mu C\ kg^{-1}$/mAs values vary more than $\pm$ 10 percent among units it will be necessary to provide a different technique chart for each unit, unless phototiming is used exclusively. The $\mu C\ kg^{-1}$/mAs in a single unit should not vary more than $\pm$ 10 percent over time.

The $\mu C\ kg^{-1}$/mAs should be measured at least annually. However, it is also an important and rapid tool to use in troubleshooting a unit which is said to be "shooting light" or "shooting dark." Tests can be made quickly with only a dosimeter and homogeneous phantom to determine whether or not the problems are equipment related and which mA and timer stations are at fault.

7.2.6 *Linearity*

If a generator is properly calibrated it is possible to select various mA and timer station combinations that produce the same mAs and

produce radiographs of similar density. The generator linearity is a measure of the ability to change mA-timer station combinations, keeping the mAs and kVp fixed, while obtaining the same x-ray output.

This test is best carried out using an accurate dosimeter. Measurements should be made at mA and timer station combinations normally encountered in the clinical setting. In addition, it may be worthwhile to make additional measurements at other kVp stations, also in the clinical range.

Federal regulations (FDA, 1986) require that all new x-ray equipment maintain linearity to ± 10 percent between adjacent mA stations. This means that if a generator has six mA stations, the total variation over the extreme range of mA's could be ± 50 percent! However it is possible to maintain the linearity to ± 10 percent (or less) over the entire clinical range of the generator, *e.g.*, 100 to 800 mA, regardless of the number of mA stations, not just from station-to-station.

This check should be carried out when generator modifications are made or generator calibration is carried out, and at least annually.

7.2.7 *Exposure Reproducibility*

Proper calibration is not of much use, if the exposures are not reproducible. In this case, reproducibility does not mean that the x-ray output is the same for three consecutive exposures at the same technique—most generators can do this. Here, reproducibility means that, within reason, the kVp, mA, and exposure time can be changed, the original technique reset (the identical kVp, mA, and time), and the x-ray output will be similar to that originally measured. A minimum of three exposure measurements should be made with all controls changed between the three exposures and the average and range determined.

Many generators exhibit problems with this test if the technique setting, *e.g.*, kVp, is selected by moving the selector from lower to higher kVp one time and then from higher to lower kVp the next. (Some generators may exhibit errors of 3 to 5 kVp under these conditions.) However, knowledge of this problem will allow the technologists to approach the desired setting from the same direction thereby improving generator reproducibility.

The exposure reproducibility should be maintained within ± 5 percent when kVp, mA, and exposure timer stations are changed between each exposure. (Exposure reproducibility is defined here as

the maximum minus the minimum exposure divided by the average of the three exposures.)

These measurements should be made for troubleshooting purposes when appropriate and at least annually.

7.2.8 *Phototimers*

Phototimers (*i.e.*, any automatic exposure control device) can provide the technologist with significant assistance in producing optimum quality radiographs when: 1) the x-ray generator is properly calibrated; 2) the proper phototimer sensor panel has been selected by the technologist; 3) the patient is positioned properly in the x-ray beam (over the appropriate phototimer sensor panels); 4) the phototimer circuits are properly calibrated for the specific intensifying screen being used (taking into account the spectral quality of the beam with varying kVp and patient thickness); 5) the part to be examined covers the entire chamber; 6) the exposure time (either extremely short or long) does not result in decreased film sensitivity due to reciprocity failure of the film (see Section 7.2.8 k).

The requirements for x-ray generator quality control as discussed previously also apply to phototimed systems. The items concerning sensor selection and patient positioning are dependent on the technologist and must be approached through education and proper motivation. The fourth item, proper phototimer circuit calibration, is essential to ensure that diagnostic quality films are produced consistently, even if the other three items are properly controlled.

To evaluate properly the phototiming circuits the following must be investigated:

a. *Sensor panel location*—it is necessary to ensure that the phototimer sensor panel location indicator is positioned accurately relative to the actual panel location. If this is not the case then film density may be erratic due to improper positioning of the body part being radiographed.
b. *Minimum exposure time*—if kVp and mA are selected such that the system requires an exposure time shorter than the minimum capability of the system the films will be inconsistent and dark.
c. *Back-up, or maximum, exposure time*—if the phototimer circuits should fail or a technique be selected which would lead to an extremely long exposure time, the exposure should be automatically terminated at some preselected time or mAs.
d. *Proper phototimer sensor panel function and selection*—most

phototimers have three panels which are selected at the x-ray generator control panel by the technologist. It is necessary to verify that the sensor panel or panels selected are being used and that the other panel(s) are disabled. In addition, it should be verified that each panel, or combination of panels, provides the same exposure or exposure time for a set kVp, mA and patient thickness.

e. *Proper phototimer correction circuit function with kVp*—since screen sensitivity varies with kVp, it is necessary to have circuits to compensate for this variation and ensure that proper film density is obtained regardless of the kVp selected. This should be evaluated using a patient equivalent phantom (15 cm of plexiglas or acrylic is equivalent to a 21-cm patient thickness) for kVp's throughout the clinically used range.
f. *Proper exposure for various mA stations*—if the mA is varied, the phototimer circuits should terminate the exposure so that the same x-ray exposure reaches the screen-film system, assuming constant kVp and phantom thickness.
g. *Proper exposure for various field sizes*—if the field size is varied the phototimer circuits should compensate for the differences in scatter and geometry so that the same film density is obtained, as long as the detector chamber is in the field.
h. *Phototimer reproducibility*—if several exposures are made at the same kVp and mA, and with a phantom of the same thickness, the phototimer system should provide the same exposure to the patient and produce films of the same density.
i. *Density control function*—most phototimers have a series of buttons to allow for the production of lighter or darker radiographs at the option of the technologist. These should be tested to ensure that they do indeed increase or decrease the exposure, and by similar amounts for each step and in each direction.
j. *Proper phototimer calibration with patient thickness changes*—changes in the thickness of the patient also affect the spectral distribution of the x-ray beam. Consequently, it is important to evaluate films produced with the range of patient thicknesses typically encountered clinically at a mid-range kVp as well as at the extreme kVp's. Low kVp's should be used if the unit is used primarily for pediatric studies or mammographic imaging.
k. *Reciprocity law failure*—the reciprocity law for photographic materials indicates that the same photographic result should be obtained as long as the product of the intensity (of light) and exposure time is the same, regardless of the length of the exposure time. However, photographic materials do not follow the reciprocity law, but exhibit reciprocity law failure (RLF). RLF

results in an apparent decrease in sensitivity of the photographic material for short (less than 0.1 second) or long (greater than 1.0 second) exposures. Consequently, RLF will become an important factor in calibrating phototimer systems when exposure times may range from a fraction of a second to as long as 5 or 6 seconds, *e.g.,* in mammographic or conventional tomographic imaging.

Control limits are not applicable to the minimum exposure time measurement, but for most modern systems the minimum time should be less than 10 milliseconds. The back-up timer shall be set so that the maximum possible exposure does not exceed 600 mAs (FDA, 1986), but it may be set at lower limits. The variation in radiation exposure for the sensor panel variation test and the phototimer evaluation at various mA stations should be ± 10 percent or less. For evaluation of kVp and thickness variation, film densities from exposure of a phantom should be at an optical density of approximately 1.20 with variation over the kVp and phantom thickness range of ± 0.30, or significantly less for well-designed generators when films are processed within hours of exposure. The total acceptable range of film density variations, including that due to the variability of the film processor, should not exceed + 0.20 in optical density from successive quality control checks for the same technique. The field size compensation circuits should be able to maintain the density variations to within ± 0.10 in density for field sizes ranging from 100 to 1200 cm^2. The phototimer reproducibility test should result in radiation exposures within ± 5 percent of the average exposure. The density control function should allow for changes in radiation exposure of approximately 25 percent for each step, and the "plus" buttons should increase the exposure while the "minus" buttons should decrease the exposure.

Special care should be taken to ensure that the same cassette is used for evaluating a phototimed system. Also, the same emulsion batch of film should be used and should be processed promptly to minimize the effects of external variables.

Abbreviated phototiming tests should be carried out every six months and should include tests 7.2.8d through 7.2.8i as described above. All of the phototimer tests noted above should be carried out annually.

7.3 Grids

Grids must be evaluated under their conditions of use for the results to be meaningful (*e.g.,* same source-to-grid distance, as a

stationary or bucky grid, at clinical kVps, and with sufficient scattering material).

7.3.1 *Grid Uniformity*

Imperfections in grids, introduced as part of the manufacturing process or during clinical use by mishandling, can produce diagnostic images with bothersome artifacts, some of which may possibly mimic lesions.

Grid uniformity can best be evaluated by producing a radiograph of a homogeneous phantom at a clinical kVp and at an exposure that produces a density of approximately 1.20 on the film. The phantom should be large enough to cover most of the grid being evaluated (at least 30 × 30 cm) and preferably large enough to cover the entire grid. The source-to-grid distance at which the grid will be used should be selected. Note that for this test and for clinical use it is essential to use a source-to-grid distance within the range specified for the grid. If an improper distance is used grid artifacts will be enhanced and grid cut-off will be apparent. The resultant film should be evaluated on a viewbox of uniform brightness.

Acceptance levels are difficult to specify, but any dark or light areas which could interfere with the diagnosis should be considered as a possible reason for rejecting the grid, especially if these areas are located in the central region of the image. Grid lines should not be apparent for bucky-grid films. In addition, the density should not vary more than ± 0.10 perpendicular to the anode-cathode axis. Light or dark strips should also be considered as a possible reason to reject a grid.

All bucky grids should be tested upon purchase *before* putting them into use and at least annually thereafter. Grid cassettes and stationary grids designed to clip onto a cassette should be checked at least every six months, if the grid appears to be damaged, or if the grid is suspected of creating artifacts.

7.3.2 *Grid Alignment*

The film produced for testing grid uniformity can also be used to assist in evaluating grid alignment. In addition to proper grid alignment the x-ray tube must be properly aligned with and at the appropriate distance from the grid (see Section 7.1.3). It is necessary to ensure that the correct side of the grid faces the x-ray tube, and that the center of the x-ray beam is aligned with the center of the grid.

Grid alignment becomes more critical for higher ratio grids, *e.g.*, 12:1 and 16:1. Also, if linear tomography is to be carried out the grid lines should be parallel to the direction of tomographic motion.

Grid misalignment normally appears as either broad strips of reduced density on the film or a tapering of density from the center to the edge, with the density decrease being perpendicular to the grid lines or septa. Similar results will be obtained if the grid is used at the incorrect distance, or if the grid is used with the "tube side" toward the film.

Grid alignment checks should be carried out at the same time and with the same frequency as the grid uniformity checks.

7.4 Cassettes, Screens, Films, and Chemicals

It is essential to have good control over the cassettes, screens, films, and chemicals before a quality control program can consistently ensure optimum images. Even though a quality control program monitors these items, technologist errors may become the major source of error, *e.g.*, selecting the incorrect screen-film combination for an examination.

7.4.1 *Screens, Films, and Chemicals*

A major aspect of quality assurance is the selection of appropriate intensifying screens, films, and processing. Various screen-film combinations allow tailoring of the screen-film speed and image quality to the specific needs of the examination. However, multiple screens and films provide opportunities for using an incorrect screen-film combination for a specific examination or for loading the wrong film in a cassette in the darkroom. The number of screen-film combinations in use in a department should be minimized, unless specific systems can be isolated in a particular area and handled in a separate darkroom, or unless different size cassettes can be used for specific examinations.

Another problem is the mixing of various brands of screens, films, chemicals, etc. For example, a department using Brand W screens, with Brand X film, Brand Y chemicals in a Brand Z processor may have difficulties obtaining appropriate technical information and support from any one of the four manufacturers. There are so many possible combinations of screens, films, chemicals and processors that no one manufacturer is likely to test all potential combinations and

be able to provide comprehensive technical support. The best advice is to select a screen-film combination for its image quality and use the chemistry and processor recommended by the film manufacturer.

7.4.2 *Screen-Film-Cassette Speed Matching*

There are two problems in screen-film-cassette speed matching: (1) matching the spectral characteristics of the light emitted by intensifying screens to the spectral sensitivity of the film; (2) matching screen-film-cassette combinations based on screen type and age and cassette type and age in order to minimize variations in film density.

Intensifying screens emit the light that is used to expose the film, and it is essential to ensure that the film is sensitive to the color of the light emitted. For example, exposing blue-sensitive film with intensifying screens emitting green light causes a portion of the light to be lost because the film is not as sensitive to light in the green part of the spectrum. Likewise, blue-light-emitting screens should not be used with green-sensitive film. Even though green-sensitive film is also sensitive to blue light, the sensitivity of the film has been designed for use with the higher energy conversion green emitting screens and thus more exposure is required to produce the same density. (The key here is to use only the screen and film combinations recommended by the manufacturer.)

7.4.3 *Screen-Film-Cassette Replacement*

The screens and cassettes in a particular work area should be of the same type and of the same age in order to avoid film density variations. It is necessary to check the speed of all screen-cassette combinations periodically and match those with the closest speed for use in one area. If possible, all screens and cassettes in one area should be replaced at one time since there are manufacturing differences between cassettes and batches of screens, and since the light emission of screens changes with time (Trout & Kelly, 1974). Screen light output is affected by temperature (Bollen, 1984), and cassettes should be stored at room temperature.

The densities of the films from similar cassettes and screens exposed under identical conditions should be within $\pm$ 0.05. Cassettes that produce film densities in excess of this range should be taken out of service or isolated for use in areas where similar screen-cassette-speed combinations can be located.

Such checks should be carried out at least annually or when there is a question concerning variation due to the screen-cassette speed.

7.4.4 *Screen-Film Contact*

The contact between the intensifying screen and film determines how much fine detail in the subject can be reproduced on the film. Poor contact reduces the image quality (sharpness) of the final radiograph. Consequently, screen-film contact is an important quality control check to ensure optimum radiographic image quality.

Cassettes with large central areas of poor contact should not be used. (Note that freshly loaded cassettes may exhibit poor contact because of entrapped air. This problem can be minimized by allowing about 15 minutes between loading and exposing the cassette.)

Screen-film contact should be checked using a coarse wire mesh, prior to use, at least once a year, when image quality appears to be degraded, or when a cassette appears to be damaged. The technologist and imaging physician should constantly check clinical films for poor contact and evaluate all problem cassettes. More information on this test is given in Appendix A.

7.4.5 *Screen Cleanliness*

Any dirt or abrasion on the screen surface will be visible on the radiograph. Screens should be inspected and cleaned regularly *only* with the cleaning solution recommended by the screen manufacturer. (In order to ensure screen cleanliness smoking, eating, and drinking should not be allowed in any darkroom.) Special attention must be paid to the cleanliness of screens used for mammography. Some mammographic imaging systems use single emulsion films, and all use high contrast films and screens capable of recording extremely fine detail. All of these factors can cause every minute particle of dust and dirt to be visible on a radiograph.

Screens can be inspected under visible light. However, ultraviolet light will cause most screens to fluoresce allowing more precise identification of flaws or imperfections and dirt on the screen surface. Further information on screen artifacts can be found in Section 21.1.

Screens should be cleaned as recommended by the manufacturer and checked for cleanliness at least every six months.

7.4.6 *Cassettes and Cassette Identification*

The cassette is an integral part of the imaging chain and is responsible for maintaining screen-film contact while preventing the film

from being exposed to room light. The cassette should identify the screen-film combination contained. If different screen-film combinations are used in the department then each cassette containing a particular combination should be distinctively marked so that it is virtually impossible for the technologist to use the wrong cassette for an examination. In addition, each cassette should be marked in such a way that the individual in the darkroom can clearly identify the particular cassette so that it will be loaded with the proper film.

Each cassette should be assigned a number, and this number should also appear on the screens in indelible ink, or a lead number should make a readable image on the radiograph. This allows for an inventory of the cassettes and a record of the age of the screens. Also, it is possible to look at a clinical radiograph and determine which cassette may need to be cleaned, checked for screen-film contact, or replaced.

Any cassette which has had liquid spilled on it, be it coffee or contrast media, should be thoroughly cleaned and radiographically checked to ensure that artifacts have not been introduced.

The imaging physician should be constantly on the alert for evidence of screen and cassette problems when interpreting radiographic studies.

7.5 Film Evaluation Following Radiograph of a Phantom

After all quality control tests are performed on any radiographic imaging system it is essential to ensure that the proper images can be produced. Consequently, it is necessary to make one image of a patient equivalent phantom to determine whether the film produced is of the proper density and the radiograph is uniformly exposed. Measurement of the entrance exposure to the phantom provides a means for monitoring patient exposures periodically for a single room or among rooms to ensure that all radiographic rooms use similar exposures for the same procedure, or that the reasons for differences in exposures are understood.

In addition to using this test as the last quality control check in a room, it is also a valuable test when troubleshooting a problem. Often making a radiograph of the same phantom and comparing the film densities and entrance exposure will indicate whether the problem is due to equipment or personnel.

7.5.1 *Exposure per Film*

A patient equivalent phantom (approximately 30 × 30 cm) can consist of a container of water, acrylic material, or any material

which has absorption and scattering characteristics similar to the human body. It may be homogeneous or contain test objects but there must be sufficient uniform area so that differences in density both parallel and perpendicular to the anode-cathode axis are evident. A simply constructed homogeneous phantom that can mimic several different body parts is described by the American National Standards Institute (ANSI, 1982).

A radiograph of the patient equivalent phantom should be made while the entrance exposure is being measured. The x-ray exposure and film density, as measured in the center of the film, should be recorded as part of the room quality control record. The film should be visually checked to ensure that the density is relatively uniform from side to side.

The density measured in the center of the film (simulating the AP lumbar spine) should be approximately 1.20 ± 0.15. The film density perpendicular to the anode-cathode axis should not appear significantly different than the density parallel to the anode-cathode axis when viewed on a conventional viewbox. The typical range of entrance exposures in air for an AP lumbar spine exam from the 1979–1981 Nationwide Evaluation of X-Ray Trends (NEXT) data is from 100 to 150 $\mu C\ kg^{-1}$ (400 to 600 mR) (FDA, 1984a).

The FDA has recently published recommendations regarding evaluation of radiation exposure from diagnostic radiology examinations (FDA, 1985a). It is recommended that staff be aware of the amount of radiation which would be received by a patient for each common radiographic projection used and examinations conducted in a facility. These exposures should be compared periodically with those exposure levels considered "generally accepted." If the facility's exposure levels consistently fall outside the ranges of exposure values "generally accepted" then the facility's staff should take action to bring the exposures to within these ranges. A publication is available outlining measurement techniques (Manny and Burkhart, 1985) and "generally accepted" ranges are provided in 3 FDA publications (Burkhart, 1983; FDA, 1985b; 1985c). The measurement of exposure per film in each room in the facility will greatly assist in the evaluation of radiation exposures from diagnostic radiology examinations.

With equipment used for a wide range of radiographic imaging, *e.g.*, pediatric imaging as well as adult imaging, it will be necessary to image two or three phantoms representing the average as well as the extremes in patient sizes.

This test should be a part of each quality control check and when troubleshooting equipment problems.

7.5.2 *Matching Images and Exposures*

The density of all patient-equivalent-phantom films produced by different units should be within ± 0.15 of the average density of all the films. [For the ANSI phantom (15 cm of acrylic and 3 mm of aluminum) the technique for a 21 cm lumbar spine examination should be used.]

The entrance exposures should be within ± 10 percent of the average exposure for identical rooms, *i.e.*, for rooms with the same type of generators, x-ray tubes and collimators, tables and grids (using the same screen-film combination). For rooms utilizing different equipment the entrance exposures may vary more than this but an attempt should be made to understand the reasons for these differences. For example, differences in table top thickness or material and differences in grid ratio or interspace material will result in differences in patient exposures, variations that may have to be accepted. However, if the difference in exposure is due to differences in HVL or technique factors then, it should be possible to reduce the variations by standardizing these parameters.

8. Quality Control in Fluoroscopic and Cine Imaging

Other than angiography and tomography, fluoroscopy produces the highest exposure to patient and staff of all radiographic imaging procedures. Most fluoroscopic systems operate under automatic brightness or exposure control so that patient and staff exposure rates can increase without the knowledge of the individuals operating the equipment. It is possible, for example, for the kVp to drift to lower values while the automatic exposure system increases the mA to maintain adequate image quality; the result is unnecessary radiation exposure of the patient. Incorrect set up or drift of the video camera is often compensated by adjustments to the video (TV) monitor, and the result is poor image quality. Consequently, it is essential to monitor regularly the exposure rate and image quality for all fluoroscopic and cine systems, both permanent and mobile.

Many of the quality control tests for conventional radiographic imaging systems such as measurement of kVp, focal spot size, and filtration apply to fluoroscopy. In addition, it is necessary to check many other parameters related to exposure control, the video image (and recording) system, and film recording equipment.

Proper, repeatable positioning of test equipment and duplication of x-ray tube and fluoroscopic tower geometry for each test is critical since relatively short distances are often used between the x-ray tube and image intensifier input surface, and small field sizes are used. Also, it is often useful to have a service engineer available while doing fluoroscopic quality control tests, since there are many interdependent factors, *i.e.*, a change in one parameter may affect other parameters. Consequently, it is not worthwhile to continue a quality control check if major errors are found in some tests, *e.g.*, the standard fluoroscopic exposure rate of the kVp calibration.

Most quality control checks of fluoroscopic imaging equipment should be carried out at least every six months due to the complexity of the equipment. Quality control of clinical images should be done regularly. Quality control checks may have to be done more often, if problems are frequently encountered or in areas where equipment

availability and image quality are more critical, *e.g.*, in a special procedures laboratory.

8.1 X-ray Tubes, Collimators, and Generators

Many of the tests for quality control purposes on conventional radiographic equipment must also be carried out on fluoroscopic and cine equipment. For specific information on these tests refer to Section 7. The following tests should be included as part of the fluoroscopic and cine quality control procedure:

7.1.1	Filtration
7.1.4	Focal spot size
7.1.5	Visual checks
7.1.6	Mechanical and electrical safety checks
7.1.7	X-ray tube heat sensors
7.1.8	Off-focus radiation
7.2.1	Overload protection
7.2.2	kVp
7.2.4	X-ray output waveforms
7.2.7	Exposure repeatability
7.2.8	Phototimers
7.3.1 and 2	Grid uniformity and alignment

All of these tests should be carried out at least every 6 months on cine and fluoroscopic imaging systems.

8.2 Exposure Rates and Exposure

8.2.1 *Maximum Fluoroscopic Exposure Rates*

Federal regulations (FDA, 1986) require that the maximum exposure rate should not exceed 1.3 mC kg^{-1} min^{-1} (5 R/min) for manual systems or 2.6 mC kg^{-1} min^{-1} (10 R/min) for systems operated in the automatic exposure rate mode.

Standard fluoroscopic exposure rates for the average sized patient can range from 0.26 mC kg^{-1} min^{-1} to 1.3 mC kg^{-1} min^{-1} (1 R/min to 5 R/min) or more. With fluoroscopic examination times on the order of 5 minutes, or possibly more, entrance exposure to the patient can range up to 6.5 mC/kg (25 R), for the *average* size patient. [Seldom is the entire exposure given to a single area of the body so the actual

absorbed dose to the patient will be lower than 25 cgy (25 rads). In some procedures, such as interventional procedures, entrance doses of 26 mC/kg (100 rads) or more can be given. If the generator is not working properly, the exposure rate for an obese patient, or for lateral and oblique projections on the average size patient, could easily reach 5 to 8 mC kg^{-1} min^{-1} (20 to 30 R/min) or more, with a proportional increase in exposure to the staff. Consequently, it is essential to check the maximum fluoroscopic exposure rate regularly.

A dosimeter, capable of measuring exposure rate, and two 3-mm thick sheets of lead (to cover the input of the image intensifier) are needed for this test. The geometry for the test is described in the Federal Regulations (FDA, 1986).

This test should be carried out at least every 6 months and whenever service work is performed on the fluoroscopic system.

8.2.2 *Standard Fluoroscopic Exposure Rates*

The maximum fluoroscopic exposure rate ensures that a specific exposure rate will not be exceeded but does not assess the normal operating exposure rate for individual fluoroscopic systems. The standard fluoroscopic exposure rate procedure ensures that the exposure rates for specific patient sizes and kVp's will be at appropriate levels thereby optimizing the contrast of the image while minimizing patient exposure.

For this test, a dosimeter capable of measuring the exposure rate and a homogeneous-patient-equivalent phantom are required.

The exposure rate required for fluoroscopic systems is affected by age, design, kVp, and filtration. Most fluoroscopic systems should be able to produce adequate images with entrance exposures of 0.5 to 0.8 mC kg^{-1} min^{-1} (2 to 3 R/min) in the 15 cm (6 inch) mode and 0.4 to 0.7 mC kg^{-1} min^{-1} (1.5 to 2.5 R/min) in the 23 cm (9 inch) mode without a grid for a 21-cm patient-equivalent phantom [15 cm (6 inch) of acrylic and 3 mm of aluminum]. The entrance exposure rates for systems operating with a grid in place will be about 1.5 to 2 times higher. The use of grids can be eliminated for fluoroscopy as well as for photofluorospot filming with a resultant exposure reduction by a factor of about two (Gray and Swee, 1982). The exposure rates for a single room should be constant. Differences in exposure rates exceeding $\pm$ 25 percent among rooms should be investigated.

This test should be carried out at least every six months and whenever service work is performed on the fluoroscopic system.

8.2.3 *Spot Film and Spot Film Cameras*

The exposures for conventional spot films (screen-film images) are determined by the speed of the image receptor, the kVp, and the grid. The exposures for spot film camera images [photofluorospot (PFS) film cameras] that record the image from an image intensifier depend on these and other variables and on the aperture of the camera-lens systems. A small aperture will require greater patient exposure and produce a low noise image, while a larger aperture will reduce the exposure and produce a noisier image, a trade off worth considering. In order to obtain optimal image quality while minimizing patient and staff exposure it is necessary to ensure that the appropriate patient and image intensifier entrance exposure are being used, while, at the same time, assuring that the film density is appropriate for the examination.

A word of caution is in order concerning the use of these systems during examinations using contrast media. If the automatic exposure control system detector is covered by a bolus of barium or by a contrast-medium-filled bladder in a pediatric cystogram, the kerma for a single image may be as high as 0.5 to 1.5 mC kg^{-1} (2 to 6 R) (Gray and Swee, 1982), even though the entrance exposure to the patient for an image without barium may be only 13 to 26 μC kg^{-1} (50 to 100 mR) for PFS images.

Typical image intensifier entrance exposure should be in the range of 13 to 52 nC kg^{-1} $image^{-1}$ (50 to 200 μR/image) depending on image intensifier size and film quality requirements. Angiographic systems may need more exposure than this to reduce the image noise.

If the image intensifier entrance exposures exceed this range, it will be necessary to obtain the services of a radiological engineer and/or medical physicist to adjust the system. This should be done *before* making any measurements of patient entrance exposure.

The film density obtained when a uniform capacity and thickness phantom is used should be about 1.20 $\pm$ 0.15. For conventional spot films, the film density should be relatively uniform from side to side. The density of PFS spot films will decrease toward the edges, depending on the size of the image intensifier and imaging geometry, but the decrease should be similar in all directions.

Exposures for conventional spot films will depend on the screen-film system and kVp used. (See Table 8.1 for some typical entrance exposures for screen-film and PFS images.)

These measurements should be carried out every six months, when service is performed on the spot-film systems, and when patient exposure changes are suspected.

TABLE 8.1—*Typical patient entrance exposure in μC kg⁻¹* [a] for spot films[b]

	Photofluorospot Films				Conventional spot films (300 speed) with grid μC kg⁻¹ (mR)
	Without grid		With grid		
kVp	15 cm Image intensifier μC kg⁻¹ (mR)	23 cm Image intensifier μC kg⁻¹ (mR)	15 cm Image intensifier μC kg⁻¹ (mR)	23 cm Image intensifier μC kg⁻¹ (mR)	
60	25 (95)	13 (50)	44 (170)	25 (95)	117 (450)
70	17 (65)	9 (35)	27 (105)	16 (60)	69 (265)
80	13 (50)	8 (30)	21 (80)	12 (45)	44 (171)
90	10 (40)	7 (25)	17 (65)	10 (40)	38 (145)
100	10 (40)	7 (25)	16 (60)	9 (35)	34 (130)

[a]An exposure of 26 μC kg⁻¹ is equal to an exposure of 100 mR.

[b]Measurements were made with a phantom equivalent in thickness to a 21-cm patient with an 80-cm source-to-image distance and a 15-cm object-to-image distance, using a 10:1 ratio grid and a three phase generator with an HVL of 3.2 at 80 kVp. Photoflurospot film densities were all between 0.80 and 1.20 while the conventional spot film densities were all between 1.00 and 1.30. Screens used were Kodak Lanex Medium and TML film. Image intensifier entrance exposures (at 80 kVp) were 0.06 and 0.04 μC kg⁻¹ (0.24 and 0.15 mR) for the 15- and 23-cm modes respectively. Data from Joel Gray at Mayo Clinic.

TABLE 8.2—*Typical cine entrance exposure rates*[a]

	(60 Frames per second)			
	15 cm image intensifier		23 cm image intensifier	
kVp	Patient (mC kg^{-1}/min)[b]	Intensifier (μC kg^{-1}/min)[b]	Patient (mC kg^{-1}/min)[b]	Intensifier (μC kg^{-1}/min)[b]
70	13	33	8	16
80	10	34	5	16
90	8	33	4	17

[a]Exposure rates were measured using a 21-cm patient-equivalent phantom equivalent in thickness to a 21-cm patient with an 85-cm source-to-image distance and a 15-cm object-to-image distance using an 8:1 grid. Film densities were all between 0.80 and 1.20. Single frame exposure rates are approximately 9 and 4 nC kg^{-1} (35 and 15 μR)/frame at the image intensifier input surface for the 15- and 23-cm modes, respectively. Data from Joel Gray at Mayo Clinic.

[b]An exposure of 0.26 mC kg^{-1} is equal to an exposure of 1 R. An exposure of 26 μC kg^{-1} is equal to an exposure of 100 mR.

8.2.4 *Cine Film Exposures*

In order to obtain the high quality, relatively low noise images required for cardiac diagnosis, it is necessary to ensure that individual frames of film receive an adequate exposure. For cine studies the patient (and staff) exposures can become quite significant due to the large number of frames required (30 to 60 frames per second for about 10 seconds for each view or injection) in addition to the fluoroscopic exposure required for catheter placement. Patient entrance exposure may range from 13 to 39 mC kg^{-1} (50 to 150 R) or more for a study (approximately half of the exposure is from fluoroscopy and half from the cine study) so it is prudent to maintain the exposure rates as low as possible commensurate with optimum image quality.

A dosimeter capable of measuring the exposure rate of a pulsed x-ray beam and a homogeneous patient phantom are required for the test. There is general agreement that approximately 4 nC kg^{-1} $frame^{-1}$ (15 μR/frame) is required at the entrance to the image intensifier for adequate cine studies using the 23-cm mode, and 9 nC kg^{-1} $frame^{-1}$ (35 μR/frame) using the 15-cm mode (ICHD, 1983). Typical patient entrance exposure rates are given in Table 8.2.

Cine exposure rates should be measured at least every six months and more frequently in a high volume facility. In addition, they should be checked after service or preventive maintenance has been performed on the cine imaging equipment of x-ray generators.

8.3 Automatic Brightness, Exposure, and Gain Control Systems

Either automatic brightness control (ABC) or automatic exposure control (AEC) is used on most fluoroscopic imaging systems to control

the technical factors (kVp and/or mA, or pulse width) and ensure that radiation sufficient to form an adequate image reaches the image intensifier. In addition, some fluoroscopic systems are equipped with automatic gain control (AGC) which rapidly varies the gain of the video system to maintain a bright image on the video display (TV monitor). With AGC the image may become quite noisy for large patients or for oblique or lateral projections, but it will be visible.

With ABC or AEC, the system could drive the kVp and mA to high levels which would cause high patient and staff exposures. Since the kVp and mA readouts for many units are not visible to the imaging physicians, consideration should be given to incorporating digital readouts on the TV monitor during fluoroscopy along with a readout of cumulative fluoroscopic time. Proper functioning of the ABC or AEC and AGC will ensure optimum image quality at minimum exposure.

A dosimeter and homogeneous patient-equivalent phantom are required for this test.

Since there are many different types of ABC and AEC systems, it is difficult to predict exactly what results to anticipate. Base-line data can be best obtained immediately after installation or service when the service engineer can ensure that the system is functioning properly. Followup checks should produce similar results.

A test for AGC is decribed in the literature (Gray, *et al.*, 1983). AGC systems should function similarly on periodic tests, and systems designed by the same manufacturer should function similarly all of the time. A high quality AGC system should be able to compensate for at least an additional 7.5 cm of acrylic on top of the standard 15-cm phantom. In addition, the AGC should be able to compensate for the removal of 7.5 cm of acrylic from the standard 15-cm phantom.

These tests should be performed every six months, immediately after service has been performed on the fluoroscopic system, and whenever image quality appears to have been degraded (especially if the degradation is noted primarily on heavy patients, or for lateral or oblique projections).

8.4 Fluoroscopic, Spot Film, and Cine Image Size and Beam Limitation

Many factors affect the size of the fluoroscopically imaged area including the lenses, adjustments in the video camera and electronics, and adjustments of the video monitor. Each of these must be properly selected or adjusted so that all of the information present

on the image intensifier is presented on the TV monitor. The beam limitation, or collimation, must then be properly adjusted so that only the active entrance area of the intensifier is irradiated, and this collimation must function properly at all fluoroscopic tower heights.

A template with radiographically opaque markings (in inches or centimeters) is needed for this test along with a direct exposure x-ray film such as therapy localization film.

Most intensifiers display less than the specified diameter, *e.g.*, a 15-cm intensifier usually displays a 14-cm diameter field. The diameter displayed should not deviate by more than 1 cm from the specified diameter. The photofluorospot (PFS) film and cine images should be similar in size to the fluoroscopic images. The error between the non-screen film (demonstrating the x-ray beam size) and fluoroscopic image areas in the total width or length of the x-ray field should be no greater than three percent of the source-to-image distance for each mode in multi-mode systems and for any tower height (FDA, 1986). In addition, the sum of the absolute values of the x-ray field and image receptor size differences for length *and* width must be no greater than four percent of the SID. However, many systems collimate the conventional spot film to the same field size as that used during fluoroscopy.

An easy way to ensure correct collimation is to adjust the collimator leaves so that they are just visible inside the edges of the image. Proper collimation is being maintained, if the collimator leaves are visible throughout the procedure, including while raising and lowering the fluoroscopic tower.

Image size and beam limitation should be checked every six months, after service to the imaging chain, and if a change in image size is suspected.

8.5 Fluoroscopic, Spot Film, and Cine Resolution and Distortion

Resolution can be affected by many components in the imaging chain including the focal spot, imaging geometry (source-to-object and source-to-image distance), the quality and focus of the optical system, image intensifier, video camera, and television monitor and, for conventional spot films, screen-film contact. (Note that the evaluation of screen-film contact is discussed in detail in Section 7.4.3) Distortion (pincushion or barrel), or stretching of the image, can be caused by the image intensifier tube, optics, video camera and cir-

cuitry, and television monitor. Since distortion can affect resolution these two items should be evaluated together.

Two types of resolution are of interest: 1) high contrast resolution; and 2) low contrast resolution. High contrast resolution describes the ability of the imaging system to reproduce a series of thin lines and spaces which are practically black lines and white spaces in the image. Low contrast resolution is the ability to resolve relatively large objects that differ slightly in radiopacity from the surrounding area. Many medical imaging systems are not used to image high contrast information but rather must produce high quality images of low contrast objects, *e.g.*, small vessels filled with contrast material. The high contrast resolution may not predict the ability of an imaging system to reproduce small, contrast-filled vessels due to the effect of noise [both quantum mottle (the variation in optical density of a uniformly exposed radiograph that results from the random spatial distribution of the x-ray quanta absorbed in the image receptor) and electronic noise], excessive scattered radiation, or flare in the optical system. Consequently, it is necessary to make use of these two different measures of image quality.

High contrast resolution is usually measured without a phantom or scattering material in the beam by the use of resolution patterns such as a copper mesh pattern or a relatively thick (0.05 to 0.10 mm) lead resolution pattern at a relatively low (50 to 60) kVp. Low contrast resolution may be measured with patterns such as a relatively thin (0.01 to 0.02 mm) lead resolution pattern with some additional scattering material or with a penetrometer consisting of two 2 cm aluminum plates and a 1 mm aluminum sheet containing holes ranging in size from 1.0 to 7.0 mm.

For most image-intensifier-based systems in the 15- or 23-cm modes, resolution patterns with a maximum frequency of 5.0 cycles per millimeter (c/mm) are adequate. If copper mesh patterns are to be used, the pattern should contain at least 15 to 20 mesh per cm for fluoroscopic systems and at least 25 mesh per cm for cine and PFS film devices. For distortion measurements, a coarse copper mesh, such as a screen-film contact mesh or a copper mesh with 7-mm spacing between the wires, can be used.

Both low and high contrast resolution will vary from the center to the edge of the image and on the image receptor, *i.e.*, video camera, cine camera, or photofluorospot film camera. The resolution of a conventional screen-film spot film imaging system will be limited by the intensifying screens used and the screen-film contact. Table 8.3 provides typical resolutions expected for both low and high contrast resolution under various imaging conditions *with the resolution pattern as close to the image intensifier input as possible.* Resolution

TABLE 8.3—*Typical low and high contrast resolution*[a]

	15-cm intensifier				23-cm intensifier			
	Low contrast		High contrast		Low contrast		High contrast	
	Center	Edge	Center	Edge	Center	Edge	Center	Edge
	Lead targets (cycles per mm)							
Fluoro	0.80	0.60	1.88	1.69	0.70	0.60	1.23	1.23
Cine	1.60	1.40	3.40	3.10	1.40	1.20	2.58	2.08
PFS	1.40	1.20	3.15	2.80	1.20	1.00	2.80	2.50
Screen-film	3.70		4.60					
	Copper mesh (wires per inch)							
Fluoro			40	35			35	30
Cine			60	50			50	40
PFS			60	50			50	40

[a]For high contrast resolution, 0.05-mm thick lead resolution targets were used at 60 kVp with no scatter material (targets were in contact with image receptor). For low contrast resolution a 0.01-mm thick lead resolution target was imaged at 80 kVp with a 21-cm patient-equivalent phantom for scattering material. Mesh resolutions were measured using copper mesh at 60 kVp with the patient-equivalent phantom. The screen-film system for the conventional spot films was Kodak Lanex Medium screens with TML film. Exposures were the same as those noted in Tables 8.1 and 8.2. (Personal communication from Joel Gray at Mayo Clinic.)

should also be measured for geometry simulating clinical use to determine the effect of the x-ray tube focal spot on image quality. Resolution measured in this manner will be less than that noted in Table 8.3 but should remain the same over time.

It is difficult to quantify the amount of acceptable distortion. However, the distortion should be vertically and horizontally symmetrical and should appear the same for fluoroscopic, cine, and photofluorospot film images produced from the same image intensifier. Similar distortion for similar types of imaging systems is anticipated.

Resolution and distortion should be checked every six months for conventional radiographic and fluoroscopic rooms, after imaging system service, and when image quality degradation is suspected. For special procedures rooms, this check should be carried out at least every six months and more frequently for high volume facilities. For cardiac catheterization laboratories, a resolution pattern and patient identification information can be imaged together on the cine film before the start of each procedure, providing for continuous monitoring of image quality.

8.6 Image Lag

Lag is a phenomenon associated with video imaging systems and can best be described as a smearing, or comet tailing, of an image as

the camera (or fluoroscopic tower) is moved rapidly, especially past a bright light or an area with a high radiation level. This is best exemplified, in an exaggerated way, by the long streaks of light which are often seen on broadcast television when the camera moves rapidly past street or other bright lights in night scenes. In diagnostic imaging, lag results from any motion relative to the anatomy of interest, *e.g.*, from rapid movement of the fluoroscopic tower or from motion of a contrast filled vessel. In all cases, increased lag can degrade the quality of the fluoroscopic image.

Lag depends on many factors. Different types of camera tubes and targets will exhibit different amounts of lag, *e.g.*, a vidicon will normally exhibit more lag than a plumbicon. Lag is a function of the amount of light (or bias light) reaching the photocathode, and the lag increases as less light is available to form the image. Decreased target voltages can increase lag. Lag will often increase as the camera tube ages, but this normally takes two or three years to become evident.

A video camera with lag will integrate several frames, or more, of the video image reducing the effect of quantum mottle and, in some instances, allowing operation at lower exposure rates. If lag is to be used in this manner, a video camera tube with characteristically high lag should be chosen since "detuning" a camera to increase the lag may also seriously degrade other important image quality factors.

The quantitation of lag is an accepted practice in the broadcast industry where lag is defined as the percent video signal remaining in the third video field after light is removed from the photocathode. Normally this requires the use of a video disc recorder or a video tape recorder which can accurately display single video fields. A technique for measuring video lag in fluoroscopic imaging systems, which requires the use of a conventional storage oscilloscope and a lead shutter mechanism, is described by Gray *et al.* (1984a).

The amount of acceptable lag will depend on the application of the video imaging system and the personal preferences of the imaging physician using the system. Table 8.4 gives suggested amounts of lag for some diagnostic x-ray procedures.

Lag should be measured any time a new video camera tube is installed or any adjustments are made to the video camera or electronics. In addition, lag should be measured as part of the fluoroscopic system quality control check every six months and when lag is suspected to be a problem.

8.7 Flare

Flare is additional scattered or reflected light within the imaging system which reduces contrast (as scattered radiation does), and it

TABLE 8.4—*Suggested control limits for lag*[a]

Application	% Lag (Maximum)
Cardiac diagnosis	<10
Cardiac fluoroscopy	10
Neuro and vascular radiology	10
GI studies	20
Pediatrics	30[b]
Urodynamics	30[b]
Orthopedics and positioning	30–50[b]

[a]From Gray *et al.*, 1983.

[b]Minimizes patient and staff exposures by allowing increased lag to smooth apparent image noise but may result in blurring of moving objects.

is an important, though often overlooked, degrading element in any image intensifier, optical or video imaging system. Light may be reflected from the glass surfaces in the imaging chain (each lens has three to six elements, which means there may be up to 12 reflective surfaces), from the edges of any lens that has not been properly blackened, or from any surface within the intensifier, lens, or video camera that has not been painted with flat black paint. Scattered light results, most often, from dust or smoke residue on glass surfaces.

Typically, a lead disc, that is equal to 10 percent of the image intensifier input surface diameter, is imaged on film or with the video system. The amount of flare is then determined with photographic film (Moore, 1981, 1982; Rossi and Bromber, 1982) or with a video waveform monitor and analysis of the video signal (Gray *et al.*, 1983).

Many factors affect the amount of flare, including the age of the image intensifier, with flare often increasing with age. However, newer image intensifiers exhibit less flare due to improvements in design. Table 8.5 (Moore, 1982) indicates the amount of contrast found for imaging systems in cardiac catheterization laboratories. Contrast is defined,

$$\text{Contrast} = \frac{L_{max} - L_{min}}{L_{max} + L_{min}} \times 100\%,$$

where L_{max} is the luminance in the center of the intensifier output without a lead disc and L_{min} is the luminance behind the lead disc. (The disc should cover 10 percent of the image area and be about 3-mm thick.)

Imaging system flare should be measured as part of the acceptance

TABLE 8.5—*Image intensifier contrast ratings*[a]

Contrast range	Number of intensifiers
Pre-1979	
Less than 57%	0
57–63%	6
64–76%	19
77–83%	6
1979–1981	
Less than 65%	1
65–70%	6
71–83%	32
84–90%	5

[a]From Moore, 1982.

testing of a new room and periodically. Flare should be measured more frequently where low contrast detectability is important, *e.g.*, every three to six months in a cardiac catheterization laboratory. In addition, it should be measured any time the contrast of the image appears to have decreased and when maintenance is performed on the imaging chain.

8.8 Relative Conversion Factor of Image Intensifiers

The conversion factor of an image intensifier is a quantitative measure of the efficiency with which the intensifier converts x rays to light and is normally expressed as a ratio of output luminance (candela/m^2 in SI units or nit, as recommended by the International Commission on Illumination) to exposure rate, or

$$\frac{\text{nit}}{\mu\text{C/kg s}^{-1}} = \frac{\text{cd m}^{-2}}{\text{mR s}^{-1}}.$$

[Photometric units are discussed in detail in the Handbook of Optics (Driscoll, 1978) and SPSE Handbook of Photographic Science and Engineering (Thomas, 1973).] This ratio depends on the energy of the x-ray beam and absorption characteristics of the intensifier input phosphor, the electronic gain (or amplification) of the intensifier, and the (electron to light) conversion efficiency of the output phosphor. Each of these can vary among tubes and can change with time, as well as with the gain resulting from the reduction in the image size. A decrease in the conversion factor will require an increase in radiation level to produce the same brightness on the television monitor

or the same density on film, unless a compensating change is made in the aperture of the video or spotfilm camera.

It is difficult to measure the *absolute* conversion factor but easier to measure the *relative* conversion factor. Since this is a relative number it cannot be used to compare intensifiers (unless they are identical image intensifiers with the same optics), but it can be used to track the efficiency of the image intensifier over time. It should be noted that this is not a quality control check but a diagnostic test that provides information to assist in troubleshooting system problems.

This measurement should be done with the assistance of an x-ray engineer since it is an invasive test and requires removal of the video camera. The video camera tube can be easily damaged by accidental exposure to room light when the video system power is on.

The relative coversion factor is measured at a set kVp using a specific geometry. It is recommended that the kVp be similar to that used for fluoroscopic imaging (80 kVp) and that the x-ray beam pass through a patient equivalent uniform phantom. (Note: this produces a beam hardness typical of the clinical imaging situation, but the conversion factor reported by the manufacturer is normally measured under different conditions.) In addition, there are three quantities which must be precisely controlled or measured: 1) the area of the intensifier irradiated; 2) the intensifier entrance exposure rate; and 3) the amount of light from the output of the intensifier.

There are few data available to determine acceptable variation in the relative conversion factor. However, Gray has found that variations of ± 50 percent are common for identical systems, though some of this variation may be due to differences in the ages of the intensifiers.[4]

The major reason for monitoring the relative conversion factor is to determine its change with the age of the intensifier. A rapid decrease in the conversion factor is noted over the first few months after installation of a new intensifier followed by stabilization at 50 to 75 percent of the initial value for long intervals (two to three years). As the tube nears the end of its useful life, a rapid decrease is again noted.

The relative conversion factor should be measured as part of the system acceptance test and six months later to obtain baseline data and thereafter only if problems are noted that may be related to a decrease in the conversion factor, *e.g.*, when the ABC system increases the exposure rate for no obvious reason.

[4]Personal communication from Joel Gray at Mayo Clinic.

8.9 Cine Projectors

Every element in the imaging chain is important if a quality image is to be displayed for diagnostic purposes. For cine systems, the projector is as important as the cine camera or film processor. The final image can be degraded by dirty projector optics which increase scattered light and flare and, in turn, reduce contrast. Erratic motion of the film in the projector film gate (jitter) will reduce resolution. Improper viewing conditions, reduced projector lamp brightness, projector optical distortion, or a poor quality or dirty projector screen will all degrade the quality of the final image.

The projector optics should be cleaned at least every six months and more frequently for projectors which are used regularly. Special attention should be paid to the optics near the film gate which can become coated with film residue and can be scratched. (Scratched lenses should be replaced as soon as possible.) The surfaces of the polygonal prism should be cleaned as should any other glass surfaces that can be reached without disassembling the optical elements. Only lens cleaner produced for cleaning camera optics and the appropriate lens tissue should be used for cleaning optical surfaces. The appearance of the projection bulb should be checked frequently since metallic deposits often develop on the inside of the bulb, and these deposits reduce image brightness.

The quality of the projector screen can be checked visually and the amount of light produced by the projector source may be monitored with a photometer. The projector lamp should be replaced when the output falls below an acceptable level.

Projector image quality (focus, resolution, and distortion) as well as the stability of the film in the film gate can be evaluated using inexpensive, monochrome, motion picture test films available from the Society of Motion Picture and Television Engineers (SMPTE, 1983). Special attention should be paid to the focus and image quality over the entire field, since a slight misalignment of any one of the many optical elements may result in loss of sharpness in some areas of the image while other areas retain their image quality.

Acceptance limits are difficult to set for projectors since most manufacturers provide no technical information about projector image quality. However, any cine projector in use today should be able to resolve all resolution elements in the SMPTE test films, and the jitter of the image due to film instabilities in the film gate should be minimal. (Note that if the SMPTE test film indicates minimal or no jitter, but jitter is apparent in clinical images the cine camera is probably the source of the problem.)

The test films should be projected and the results evaluated at least every six months and more frequently for busy facilities.

9. Mobile Radiographic, Capacitor Discharge, and Fluoroscopic Systems

Capacitor discharge equipment, whether permanently installed or mobile, will be discussed together, since these units share unique problems. Many tests described in previous sections are applicable to capacitor discharge equipment. However, due to specific limitations of capacitor discharge generators some difficulty will be encountered in testing these systems and different acceptance limits may apply.

Mobile radiographic and fluoroscopic systems present special problems which will be discussed in this section. However, most of the tests previously described for general radiographic and fluoroscopic systems, as well as the acceptance limits, are applicable to mobile equipment.

All mobile equipment should be used with caution since appropriate grounding may not be present. It is possible, even with properly grounded mobile equipment, that a patient could receive a shock if contact were made with both the mobile equipment and another piece of electrical equipment, *e.g.,* the patient's bed. In addition, special attention should be paid to electrical safety checks recommended by the manufacturer.

9.1 Capacitor Discharge Systems

Capacitor discharge radiographic units, whether mobile or permanent, have one common problem—the peak kilovoltage drops continuously during the exposure, because current is lost during the discharge of the capacitors and the voltage across the capacitors also drops. For example, the starting peak kilovoltage may be 100 kVp but it will drop to 80 kVp at the end of a 20 mAs exposure. [The peak kilovoltage drops about 1 kV for each mAs of exposure in a unit with a 1-microfarad capacitor (Weaver *et al.,* 1978).] In addition to the difficulty in measuring the kVp of such systems, special care must also be given to preparing the technique chart with selection of an

initially higher kVp so that the average kVp is similar to that used in conventional radiographic systems.

All of the quality control tests described for general radiographic equipment should be performed on capacitor discharge x-ray systems. In general, the results of such tests on capacitor discharge systems are expected to be similar to those from permanent equipment. However, the acceptance limits for kVp calibration must be carefully set. The kVp should be measured with a noninvasive device *after* the system has been calibrated by a service engineer. The quality control test results (at a specific mAs), rather than the indicated kVp, become the operating level.

All of the applicable tests should be carried out on capacitor discharge radiographic equipment at least annually and more often on frequently used equipment.

9.2 Mobile Radiographic Systems

Mobile radiographic systems, usually referred to as "portables," are not capable of producing radiographs with the same high image quality that can be obtained from permanent radiographic equipment in the radiology facility. The limitations of "portables" include low mA (restricting the ability to eliminate motion blurring), limited exposure time selection especially at short exposure times (resulting in excessive density variation from one film to another), relatively large x-ray focal spots (limiting image resolution), and little radiation protection. Consequently, examinations using "portables" should never be requested in place of radiographic examinations utilizing permanently installed x-ray equipment, except in extenuating circumstances. For example, abdominal films require high mAs exposures. Due to the limited mA available on "portables," the exposure time usually approaches one to three seconds, with the films exhibiting blurring due to patient motion and providing less than optimal diagnostic information. Since the high-ratio grids and buckys cannot be used with portables, examinations using contrast media should always be done using permanent x-ray equipment. This assures that subtle differences in the uptake or distribution of the contrast media will be imaged with the best possible contrast.

Although mobile equipment is not capable of producing optimal image quality for many examinations, adequate quality for a limited array of examinations can be provided.

It must be stressed, however, that whenever possible the radiographs should be produced in the radiology department using per-

manently installed x-ray equipment. Mobile equipment should be used only when the patient is in an unstable condition and cannot be transported to the radiology department.

Even though we cannot expect the quality of radiographs from mobile equipment to be as high as from permanently installed equipment, in many facilities radiographs made with mobile equipment are inferior to what they could be. The tendency is to think that "because they are portable" the quality should be inferior. In some instances this may have to be accepted but the quality of the image is more likely related to the condition of the patient. Patients requiring radiographs using mobile equipment are usually the sickest and least cooperative, making good positioning and technique extremely difficult. The technologist will not try to produce a quality radiograph if the imaging physician will accept whatever is produced. The technologists need guidance from the imaging physician about the need for quality radiographs. The technologists must appreciate that the output from rechargeable mobile equipment will vary even when the indicator needle is in the "operating zone." Consequently, it is essential to ensure that the mobile equipment is maintained with a maximum charge. With a *concerted* cooperative effort on the part of the imaging physicians and technologists, radiographs, produced using mobile equipment, can be of reasonable quality and in some instances can approach the quality of conventional radiographs. Finally, many mobile radiographic units are mechanically unstable with the tube fully extended, and care must be exercised when producing radiographs with the tube extended over the patient's bed, or in similar situations.

This section will discuss some limitations of the mobile radiographic system, how these limitations can be overcome, and the quality control procedures required to ensure that mobile radiographic units are operating at an optimum level.

Many battery powered systems also use the battery to drive the mobile unit. Any power used for moving the unit will not be available for producing radiographs, so special care must be taken in evaluating battery operated power driven units. Gray *et al.* (1983) describe a procedure for evaluating the effect of the power drive unit on radiographic output.

For best results, it is advisable not to use the power drive system more than necessary. For example, the mobile unit should be stored as close as possible to the areas in which it is used. In addition, the battery charging system should be plugged in, and activated, whenever the unit is not in use ensuring that the batteries are fully charged when the unit is needed. Nickel-cadmium batteries should be removed from the unit, evaluated, serviced, completely dis-

charged, and fully charged by qualified service personnel at least annually and more often for units that are used frequently.

Every effort should be made to provide the technologist who uses any mobile x-ray equipment with all of the tools required to ensure that the proper source-to-image distance, angulation, beam alignment, and exposure factors are being used. Particular attention should be paid to ensuring that the cassettes used for mobile radiography are not accidentally fogged while making exposures in a patient's room. Also, each mobile radiographic unit should be equipped with at least two lead aprons—one for the technologist and one for other personnel assisting the technologist.

All of the quality control tests described for general radiographic equipment should be performed on mobile x-ray systems. In general, the results of such tests on mobile equipment should be similar to those from permanent equipment. However, mobile systems do not have the extensive calibration circuits common to permanent equipment so some *minor* variations in kVp and mA calibration may have to be accepted.

All of the applicable tests should be carried out on mobile radiographic equipment at least annually and more often on frequently used equipment. In addition, any time major maintenance is performed, especially battery service, the appropriate output qualities should be evaluated.

9.3 Mobile Fluoroscopic Systems

Mobile fluoroscopic systems are similar to fixed fluoroscopic units and should perform in a similar manner. However, these systems present a special challenge in terms of radiation protection. If the technologist is encouraged to ensure that the x-ray tube is placed under the patient, or on the side away from operating room personnel for lateral projections, the amount of scattered radiation received by the operating room staff will be reduced by a factor of two or three. Also, two additional and inexpensive items may be worth adding to the fluoroscopic unit: (1) an audible indicator so it is apparent when radiation is being produced (the volume may be proportional to the radiation output level in units where the exposure rate may be selected); and (2) a fluoroscopic time accumulator which incorporates a digital display into the video display.

Analog or digital video storage systems should be considered for use with every mobile fluoroscopic system as a means of exposure reduction. "Last frame hold" features allow the surgeon to view a

static image for a long period of time without using a continuous fluoroscopic (radiation) exposure. Another means of exposure reduction is to ensure that the longest cone possible is used on the x-ray tube. An increased source-to-skin distance significantly reduces the patient exposure.

Sterile wraps should always be used when the intensifier is above, or near, the sterile field. Protective (waterproof) wraps should also be used for the portion of the x-ray system that is under the patient. This avoids contamination of the electronics with liquids, which can result in a safety hazard for the patient and staff. Failure to protect the equipment will increase the required maintenance while decreasing its useful life.

Finally, whenever mobile fluoroscopic equipment is positioned near a patient, extra care should be taken to ensure that *all* locks are properly set.

All quality control tests that are applicable to conventional fluoroscopic equipment should be carried out on mobile equipment. Analog and digital video storage units should also be evaluated at least every six months (see Section 19.4).

Mobile fluoroscopic systems should be evaluated at least every six months, after service has been performed on the fluoroscopic system, whenever image quality appears to be degraded, and when it is suspected that exposure rates may have increased.

10. Quality Control in Conventional X-Ray Tomography

Conventional tomographic x-ray units range in complexity from simple linear systems (available as options to standard radiographic apparatus) to sophisticated pluridirectional units (dedicated to tomographic imaging). Irrespective of its complexity, every tomographic unit needs a quality control program if images of highest quality are to be achieved routinely. This program should include procedures specific to tomography, as well as measures discussed earlier for general-purpose radiographic units. Only the procedures specific to tomography are described here. These procedures are described in greater detail in the literature.

The most direct approach to quality control in x-ray tomography involves the use of a tomographic phantom for evaluation of selected tomographic performance parameters. This test device should contain objects to evaluate section level and thickness, resolving power of the tomographic unit, and exposure angle, uniformity and pattern. The test device, together with a radiation dosimeter, are all the equipment needed to implement a satisfactory program in quality control for a conventional x-ray tomographic unit. The tests conducted with this equipment should be performed at least annually, and more frequently if major maintenance or performance problems are encountered with a particular tomographic unit. Additional concerns that arise occasionally with conventional tomographic units include perturbations in the tomographic section caused by warping of the film cassette and by aberrant motion of the tomographic device.

For a conventional x-ray tomographic unit, performance characteristics that should be monitored include:

1. Section level
2. Level incrementation
3. Section thickness
4. Exposure angle
5. Exposure uniformity and pattern
6. Resolution
7. Patient exposure

In general, tomographic phantoms contain various objects positioned at different elevations or at an angle with respect to the image plane. From analysis of the x-ray image of one of these phantoms, the first six characteristics listed above can be evaluated. The exposure angle, uniformity and pattern of exposure can be determined by analyzing the image of a hole in a lead sheet positioned outside the tomographic plane. Section level, level incrementation and section thickness can be assessed by exposing a mesh pattern and markers oriented at 45° with respect to the image plane. Spatial resolution can be estimated by determining the smallest spacing visible in an image of mesh patterns with different spacings. The radiation dosimeter is used to estimate the radiation exposure to the patient during typical tomographic procedures. This dosimeter is identical to those recommended for exposure measurements for conventional radiographic units.

Performance criteria and tolerance limits for tomographic quality control tests vary somewhat with the type of tomographic unit and its performance at the time of acceptance testing. The limits described below are intended simply as a guide to acceptable performance of a typical x-ray tomographic unit.

1. *Section Level:* The agreement expected between the indicated and measured section levels varies somewhat, depending upon the type of tomographic unit. In all cases, however, agreement to within ± 5 mm should be achieved. In measurements of this characteristic the level setting should always be approached from the same direction.
2. *Level Incrementation:* In incrementing from one tomographic section to the next, level position should be reproducible to within ± 2 mm. In measurements of this characteristic, the level setting should always be approached from the same direction.
3. *Section Thickness:* This characteristic varies with the type of tomographic motion and the exposure angle and uniformity. It is recommended that tolerance limits be established for each particular unit from images compared from one set of quality control measurements to the next. In measurements of this characteristic, the thickness setting should always be approached from the same direction.
4. *Exposure Angle:* Indicated and measured exposure angles should agree to within ± 5° for units operating at angles greater than 30°; for smaller tomographic angles, the agreement between indicated and measured angles should be closer. For units employing symmetric motion at wide angles, the symmetry of exposure angle should be within ± 5° with respect to the midline.

5. *Section Uniformity:* The density of the image of the hole in the lead sheet should be nearly uniform or should vary in uniformity according to the pattern expected for the particular tomographic unit. The image should reveal no unexpected overlaps, inconsistencies of exposure, or asymmetries in motion.
6. *Spatial Resolution:* Most x-ray tomographic units should depict a 40 mesh screen pattern.
7. *Patient Exposure:* Quantitative criteria are unavailable for the levels of patient exposure expected for x-ray tomography; among identical tomographic units, patient exposure should not vary by more than 20 percent. In making exposure measurements, care should be taken to ensure that the dosimeter is positioned in the x-ray beam during the entire exposure. As a guide to exposure delivered during tomographic procedures, the data in Table 10.1 may be helpful.

Performance characteristics, the test devices required for their evaluation, and performance criteria for data collected as part of a routine quality control program are described in Table 10.1.

The actual procedures for conducting quality control tests on conventional x-ray tomographic units have been described (Littleton, 1970; Hendee and Rossi, 1979; Gray *et al.*, 1983).

TABLE 10.1—*Tomographic entrance exposures compared to non-tomographic exposures[a] (with backscatter)[b]*

Procedure		Patient Thickness (cm)	kVp	mAs	Field Size[c](cm)	Screen	Film	Entrance Exposure ($\mu C\ kg^{-1}$)[d]	Film Density	Ratio of Exposures (tomo/non-tomo)
AP Cervical	tomo	13	65	60	10×12	Lanex Reg.	3MXUD	80.24	1.38	
Spine	non-tomo	13	65	60	10×12	Lanex Reg.	3MXUD	44.12	0.98	1.82
AP Thoracic	tomo	21	68	150	10×12	Lanex Reg.	3MXUD	208.46	1.11	
Spine	non-tomo	21	68	76	10×12	Lanex Reg.	3MXUD	115.84	0.94	1.80
AP Lumbar	tomo	21	68	150	10×12	Lanex Reg.	3MXUD	207.69	1.09	
Spine	non-tomo	21	68	75	10×12	Lanex Reg.	3MXUD	115.84	0.94	1.79
AP Sella	tomo	20	65	120	10×12	Lanex Reg.	3MXUD	122.55	1.30	
	non-tomo	20	65	75	10×12	Lanex Reg.	3MXUD	94.43	1.32	1.30
Temporomandibular	tomo	15	60	120	10×12	Lanex Reg.	3MXUD	121.78	0.84	
Joint	non-tomo	15	60	84	10×12	Lanex Reg.	3MXUD	80.24	0.77	1.52
Inner Ear	tomo	15	68	120	10×12	Lanex Reg.	3MXUD	116.36	1.20	
	non-tomo	15	68	84	10×12	Lanex Reg.	3MXUD	83.08	0.86	1.40
Excretory	tomo	21	68	112.5	28×35	X-omatic Reg.	XL	161.51	1.48	
Urography (XU)	non-tomo	21	68	70	28×35	X-omatic Reg.	XL	118.94	1.56	1.35

[a]Courtesy of J. E. Gray, Mayo Clinic, 1984.

[b]All exposures were made with an acrylic patient equivalent phantom. Source to image distance—112cm; 12:1 grids; 3.2 mm Al HVL at 80 kVp; films processed in an M8 processor using Kodak RP chemistry. All exposures, with the exception of the XU exposures, were made with a CGR stratomatic system with trispiral motion. The XU exposures were made with a Picker GX850 generator with an x-ray tube employing linear motion. Exposures were made under worst case condition, *i.e.*, the fulcrum is at the surface of the phantom so that the dosimeter indicates maximum exposure. As the fulcrum is moved into the phantom, the entrance exposure decreases, especially for smaller field sizes. Film densities are not always matched—techniques employed are those normally utilized at the Mayo Clinic.

[c]In film plane.

[d]26 $\mu C\ kg^{-1}$ = 100 mR.

11. Quality Control in Mammography

Because of the subtle changes that pathological conditions introduce into the mammographic image, the application of quality control procedures to mammography has received considerable attention over the past few years. This attention has been accentuated by the relatively high doses delivered by certain mammographic procedures in the past, by the susceptibility of breast tissue to the induction of cancer at high radiation doses (BEIR, 1980), and by the use of x-ray mammography as a screening tool for detection of breast cancer in asymptomatic women (Upton *et al.*, 1977; Boice *et al.*, 1979). Publications are available that address the topic of mammographic quality control, including two reports of the NCRP (NCRP, 1980; 1986). These reports describe the philosophy and procedures for a quality control program in mammography, and the reader is referred to them for details. Only an overview of quality control in mammography is presented here.

Table 11.1 lists mammographic performance characteristics that should be evaluated annually, preferably with the aid of a qualified medical physicist. In addition, NCRP Report No. 85 provides a checklist of major components of a mammographic system with the objective of identifying common mismatches of x-ray generators, x-ray targets, beam filtration materials and thicknesses, image receptors, compression devices and kVp settings. It is claimed that at least 35 percent of all mammographic x-ray systems in routine use do not satisfy all aspects of this checklist (NCRP, 1986). Furthermore, it is suggested that systems not satisfying the checklist often provide images of inferior quality or patient exposures that are unnecessarily high. Common mismatches include use of *modified general purpose x-ray equipment* with a tungsten x-ray target for screen-film mammography; dedicated mammographic equipment with a molybdenum x-ray target, but with insufficient (or excessive) beam filtration; improper combinations of x-ray target and beam filtration; incorrect selection of kVp to obtain optimal utilization of radiation; inadequate compression devices; improper selection of intensifying screens and x-ray film; and poorly designed grids with excessive absorption of x rays. These mismatches account for far more unsatisfactory images

TABLE 11.1—*Technical items to be evaluated in a mammography quality control program (NCRP, 1986)*

Mammographic unit
representative entrance surface exposure
type of target and filter
half-value layer
accuracy and reproducibility of kVp stations
accuracy and reproducibility of timer stations
linearity and reproducibility of mA stations
reproducibility of x-ray output
accuracy of source-to-film distance indicators
light/x-ray field congruence
focal spot size
compression device design, including breast thickness indicator
Automatic exposure control devices
reproducibility
kVp compensation
minimum response time
backup timer verification
Films, screens and cassettes
mammography film and screens
screen condition
light leaks
artifact identification and control
Film processing
an index of speed
an index of contrast
base plus fog
solution temperatures
Xerographic processing
selenium plate defects
cassette related artifacts
Darkroom
darkroom integrity
safe light conditions
View boxes
consistency of light output with time
consistency of light output from one box to another
view box surface conditions
image masking and ambient light control
The system as a whole
dose calculations
phantom imaging
retakes

and excessive radiation exposure than do variations in performance characteristics measurable by a quality control program for mammographic systems.

In general, testing procedures and performance criteria for tech-

nique variables in mammography are identical to those described earlier for conventional radiographic equipment. However, three special test devices are required (see Table A.6 in Appendix A). Traditional equipment for measurement of kVp may not be adaptable to the low kVp settings employed for mammography. Test devices for kVp measurements in the mammographic range are available, however, and use of one of these devices is essential to an adequate quality control program. Similarly, many radiation dosimeters do not respond accurately to the low energy x-ray beams employed in mammography; special low energy chambers designed specifically for mammography are required for measurement of x-ray exposure. Satisfactory chambers for these low energy measurements are available commercially. As a quality control procedure, surface exposures should be measured at least annually for mammographic technique settings employed clinically. Mammographic equipment should be chosen to provide acceptable image quality at typical average glandular dose values of 0.8 cgy (0.8 rad) or less for xeroradiography or screen-film mammography with a grid, or 0.2 cGy (0.2 rad) or less for screen-film mammography without grid, for a two-view examination of the average patient having 4.5 cm-thick compressed breasts (NCRP, 1986).

Although many phantoms have been designed to measure high and low contrast resolution in mammography, none has been found *entirely* satisfactory. Nevertheless, some type of mammographic phantom should be used periodically (at least annually) for quality control evaluation of the unit. Such a phantom should not be used, however, to establish clinical exposure techniques; this practice can lead to suboptimal image quality and excessive patient exposure (NCRP, 1986).

Special attention should be paid in mammography to monitoring processing techniques to ensure the production of images of optimal quality. Procedures for film quality control are described in Section 5 of this report; procedures for quality control of xeromammogramic processing are described by Jaeger *et al.*, 1978. Of particular importance is the inspection of each xeromammographic image as a retrospective method to identify the presence of selenium plate defects and cassette-related artifacts.

12. Quality Control in Dental Radiography

12.1 Introduction

Many medical quality control programs require extensive monitoring and are often more sophisticated than necessary for the average dental practice. The following documents are recommended for a more detailed description of the procedures for quality control discussed in this Section: (NCRP, 1973; Goldman, 1981; AADR, 1983; Mason-Hing, 1985).

While certain aspects of these established procedures may be applied to dentistry, they should be applied at levels consistent with feasibility and common sense. Initially, each dental x-ray facility should establish maintenance and monitoring procedures as outlined in Table 12.1.

12.2 Description of Quality Control Procedures for Dental Radiography

12.2.1 *Reference Film*

Reference film may be approached in two ways that are described below.

12.2.1.1 *Test Film.* Information on a monitoring device for quality control testing of dental radiographic systems is available from the American Academy of Dental Radiology (Crabtree, 1984; FDA, 1985a). With this device a test film is obtained for a standard radiographic exposure (*i.e.,* normal bitewing exam). Settings of kVp, mA and time are recorded. Film is processed, its density is compared to a slide chart provided by the FDA, and the density step number is recorded. The test film with an approximate density of "1" serves as a baseline to compare with subsequent monitoring films. If a monitoring film shows an increase or decrease of two optical density steps from the

TABLE 12.1—*An outline for establishing maintenance and quality control procedures for dental radiology facilities (AADR, 1983).*

Integrity of x-ray machine should be established to include:

a. Calibration of equipment
b. Stability of tube head (consistent repositioning)
c. Proper beam alignment and source to image distance (SID)
d. Mechanical and electrical characteristics
e. Inspection and replacement of worn-out or failed parts (certified components)
f. Manufacturer's maintenance schedule.

Proper storage and handling of films, cassettes, screens, grids, and chemicals should be established.

Correct technique charts should be posted and used, including time-temperature development, x-ray exposure factors, x-ray exposure measurements and time-temperature development.

Condition of processing tanks and automatic processor should be optimized with posted maintenance schedules.

Darkroom conditions should be optimized and include:

a. Light-tight room
b. Adequate safe-lighting
c. Cleanliness
d. Adequate temperature control of water supply.

Condition of protective devices should be optimized and include:

a. Leaded apron
b. Thyroid shield
c. Protective barriers
d. Film-holding collimators (or the equivalent).

provided stepwedge test film, the facility is alerted to a problem in the radiographic system (*i.e.*, improper storage or handling of film, malfunctioning of x-ray unit, improper positioning, poor darkroom conditions, or processing deficiencies).

12.2.1.2 *Test Radiograph.* A "good-quality" periapical or bitewing radiograph should be attached (taped) to a viewbox. The "quality" of the radiograph should be determined by the person interpreting the radiograph—the dentist. All auxiliary personnel should be carefully educated to the dentist's specific criteria for each and every dental radiograph. The reference film or films will allow the dentist, dental hygienist, or dental assistant to compare recently processed radiographs for changes in film density, contrast, resolution, or other change in image quality.

12.2.2 *Retake Record*

A daily record of all retakes should be maintained. This should include date, operator (if more than one), reason for retake, and

corrective action. Repeated errors should be identified and the system corrected or auxiliary personnel given added instruction.

12.2.3 *Effective Operation of Darkroom*

The effective operation of a darkroom depends on adequate light tightness of the room and correct safelighting procedures. To determine light tightness of the room, all lights in the darkroom should be turned off, and a small coin should be placed on top of an unwrapped intraoral dental film for five minutes. The film is then processed to determine if any light reached the film and caused a shadow image of the coin. If screen-film systems (panoramic or cephalometric) are used, their testing should be as described in Section 6.1.3.

Once light tightness of the room is established, a similar approach can be followed to determine the correctness of the safelighting for the film used. Many safelights used for periapical films are unsafe for screen and some non-screen films.

In addition, the condition and accuracy of both the timing device and the thermometer should be checked. A monthly inspection should be made of the conditions of chemical storage, frequency of changes in chemistry, and mixing protocols. A daily inspection should be made of film processing solution levels, cleanliness of counter tops, and condition of film hangers.

12.2.4 *Film Processing*

By instituting an effective processing control protocol, changes in development (due to factors such as improper temperature regulation, chemistry, etc.), may be detected in time to take corrective actions. Monitoring can detect changes before the radiograph has deteriorated in diagnostic quality. Processing solutions should be changed and replenished as recommended by the manufacturer or when there is visual evidence of reduced quality of the current film (see Section 12.2.1).

Radiographs made with screen film (for example, panoramic radiographs) are much more sensitive to changes in the chemistry and temperature of the developing solution than is direct x-ray film (Poznanski and Smith, 1968). A film from a box reserved for quality control measurements should be exposed with the use of a sensitometer. The film should then be developed, and used as a reference for visual comparison with film also exposed on ensuing days to a sensitometer and developed. This approach is generally acceptable.

However, it would be preferable to measure the density of the exposed areas of the film with a densitometer. A record should be kept of the density of a particular sensitometer step (speed index), and the base-fog level. A record should also be kept of the temperature of the developer. Measurements which are outside the tolerance limits ($\pm$ 0.1 density for a particular step) indicate problems to be corrected. See Section 6.2 for additional material on film processing quality control.

12.2.5 *Cassette and Screen*

Warped cassettes, fatigue of foam or felt compression material, worn closures, dirt, light leaks, etc. frequently produce unsharp or fogged radiographs. Poor screen-film contact can be checked by radiographing a wire mesh screen placed on the entrance side of the cassette. The film can then be observed for any unsharp areas. See Section 7.4 for additional material on cassettes and screens.

12.2.6 *Viewboxes*

The conditions under which a dentist views radiographs may influence diagnostic accuracy. Quality control testing should be carried out by visual inspection of the brightness and color of viewboxes, and, if available, use of a photographic light meter to compare light uniformity across the viewing surface. Illuminators should be cleaned, and fluorescent tubes that show blackening at the ends should be replaced. See Section 21 for additional material on viewboxes.

12.2.7 *Test of X-Ray Units*

The following tests should be performed at least once a year in order to ensure that the x-ray equipment is functioning properly. These tests should be made by, or under the direction of, a qualified expert (see NCRP, 1978).

12.2.7.1 *Leakage Radiation.* Tube head leakage limits specify that the average exposure rate over 100 square centimeters at one meter shall not exceed 26 μC kg^{-1} (100 mR) in one hour normalized to maximum current for continuous operation. Diaphragms or cones used for collimating the beam shall provide at least the same degree of attenuation as that required for the tube housing. Additional details concerning this test are given in Report No. 35 (NCRP, 1973).

12.2.7.2 *Source To End-of-Cone Distance.* Use a recommended position-indicating device (PID) to check the source to end-of-cone distance for conformity to recommendations. Machines operated at 50 kVp or less require a 10 cm (4 inch) or longer distance. Above 50 kVp, a 18 cm (7 inch) or longer distance is required. Open ended cones are preferred to those having plastic closed ends because the plastic end acts as a source of scattered radiation. The diaphragm system should be designed so that the useful beam does not strike the walls of the plastic cone.

12.2.7.3 *Beam Alignment and Collimation.* A configuration of films or a fluorescent screen can be used to check primary beam alignment and beam size. For intraoral radiography, the useful beam shall be restricted to a diameter of not more than 7 cm (2¾ inches) at the end of the cone. Panoramic unit collimators provide a narrow (1 to 2 mm) useful beam and an interlocked film carrier. For a cephalometric installation, because of the increased source-to-film distance, radiation field size should be checked at the cassette to ensure use of proper aperture (collimator) for the cassette size used.

12.2.7.4 *Beam Quality.* The total filtration consists of the inherent plus the added filtration. The beam quality can be determined from a measurement of the half value layer (HVL). See Section 7.1.1 for additional minimum HVLs as specified in federal regulations (FDA, 1986). See Section 7 for additional material on HVL and its measurement.

12.2.7.5 *Timer.* The timer should be checked and should be capable of making reproducible exposures as short as 1/60 second. A "spinning top" (consisting of a rotating opaque disk with a hole or notch in the periphery of the disk), may be used. The top is spun slowly by the operator and an exposure is made (for a specific timer setting). Developed film should indicate correct number of exposures for the selected timer setting (*e.g.*, 15 exposures for ¼ second for a 60 Hz, half-wave rectified unit).

12.2.7.6 *Exposure Switch.* The exposure switch should be checked to ensure that the switch has a circuit closing contact which can be maintained only by continuous operator pressure. Verify that the exposure switch location and/or length of the cord is arranged so that the operator, when making exposures, stands at least 2 m (six feet) from the patient, well away from the useful beam, and, preferably, behind a protective barrier.

12.2.7.7 *Radiation Exposure.* Set exposure factors so that the skin

entrance exposure on a per-film basis will fall within acceptable exposure ranges for the operating kVp. A medical physicist should measure the exposure at the end of the cone with a calibrated x-ray detection instrument. The exposure measurements may be related to typical reported values (Burkhart, 1983). The use of "E" speed film may reduce exposure to patients by 30 to 50 percent with no reduction in image quality (White *et al.*, 1984).

13. Quality Control in Radiological Special Procedures

With few exceptions, the equipment in a radiologic special procedures laboratory is similar to that used for more routine radiologic examinations. Consequently, the procedures described earlier for quality control evaluation of radiographic and fluoroscopic units are directly applicable to the special procedures laboratory. Exceptions to this generalization apply to equipment used almost exclusively in the special procedures laboratory. This equipment includes devices such as rapid film changers, cinefluorographic cameras, and various types of physiologic monitoring equipment. Quality control procedures for these devices are outlined below and in Appendix A.

13.1 Film Changers

Screen-film contact should be evaluated semiannually under static conditions with the wire mesh test object for a rapid film changer and under dynamic conditions with the frame rate at an intermediate and at maximum settings. No significant difference should be apparent in the images except possibly some loss of contact at the periphery of the images obtained under dynamic conditions. In some older film changers, loss of contact at the image center under dynamic conditions may reflect a non-correctable problem in changer design. In a similar fashion, the fluoroscopic resolution test device may be used semiannually to evaluate the high and low contrast resolution under both static and rapid sequence imaging conditions and under normal and magnified modes of imaging. There should be negligible loss of low and high contrast resolution between static and dynamic imaging modes, and the resolution should be comparable from one set of tests to the next. Differences in resolution and contact between static and dynamic imaging modes may indicate inadequate synchronization between x-ray exposure and film movement, vibration of the film changer during dynamic operation, or other factors.

An occasional problem in rapid sequence imaging is a gradual

decrease in the optical density of the images obtained over a filming interval. This problem can be identified by comparing optical densities in images obtained at the beginning and end of a typical filming interval. These images should be obtained with a phantom in the beam. For satisfactory performance, the optical densities at similar locations in the images should not vary by more than ± 0.2.

Screen-film contact, high and low contrast resolution, and constancy of optical density should be evaluated at least once every six months, and more often in high volume applications or when recurrent problems are encountered.

13.2 Cinefluorographic Units

Cinefluorographic units are complex systems that require careful monitoring of their performance and periodic preventive maintenance by a service engineer. A monitoring program is essential not only to maintain image quality, but also to ensure that exposure rates remain within acceptable limits. Cinefluorography is a relatively high exposure procedure, and it is important to remember that relatively low exposure rates at the point of measurement (the input screen of the image intensifier) reflect rather high patient exposure, with (input screen):(patient entrance exposure) ratios as great as 1:1000 (Addison *et al.*, 1978).

To evaluate the low and high contrast resolution of a cinefluorographic ("cine") unit, cine images can be obtained of test objects similar to those used for evaluation of similar characteristics for image intensification fluoroscopy. However, a finer mesh pattern (50–60) should be used. The cine image should yield the same low and high contrast resolution as that expected from the image intensifier (see Table 8.3). That is, the cine unit should introduce no detectable degradation in either the low or high contrast resolution of the image. The optical density of the cine image of the test object can be monitored as an additional check on the continuity of performance of the cinefluorographic unit. These tests should be conducted no less frequently than every six months, and more frequently (*e.g.*, monthly) if the cinefluorographic unit is used regularly. Alternatively, a simple test object that provides a continuous performance check while simultaneously serving as a patient identification system has been recommended as a useful device for cinefluorographic quality control (Gray *et al.*, 1983).

In cinefluorography, exposure rate measurements should be obtained as close to the input screen of the image intensifier as possible with

a phantom in the x-ray beam. These measurements should be made at least every six months, or more often in busy facilities, by operating the cinefluorographic camera until the automatic brightness control unit has stabilized and then recording the exposure rate at an intermediate frame rate. Exposure rate measurements should be compared to those obtained during previous quality control tests, including those obtained some time after initial calibration of the cinefluorographic unit when the imaging system was operating at a consistent level. All measurements should be obtained under identical conditions (geometry, technique factors, frame rate, etc.). Measurements should agree to within ± 10 to 20 percent and should correspond to an exposure rate 2.6 to 10 mC kg^{-1} (10 to 40 μR) per frame at the input screen under non-magnified conditions without a grid in place (see Table 8.2).

Film processing is a critical element in the production of high quality cine images. Quality control procedures for film processing described earlier should be followed rigorously in a cinefluorographic facility.

In addition to the tests described above, procedures should be established with the service engineer to clean the optical system of the image intensifier and cinefluorographic camera at least every six months. The viewing screen and the lenses and prism of the cinefluorograhic projector should be cleaned monthly, and the lenses should be examined visually for scratches and other defects regularly (see Section 8.9).

Special procedures laboratories contain a variety of ancillary equipment, such as electrocardiographic units, pressure injectors, external pacemakers, devices to measure intravascular pressure and physiologic monitors and recorders (Friesinger *et al.*, 1983). This ancillary equipment is so variable that generalizations concerning quality control are difficult to formulate. Nevertheless, a quality control program for this equipment is strongly recommended. In many cases, satisfactory procedures are described in the operating manual for the equipment; in the remainder of situations, quality control procedures should be established in consultation with the medical physicist and the service representatives for the equipment. For pressure injectors, for example, periodic tests should be made of injected volume and injection time, using procedures (catheter bore, length, and aperture characteristics; formulation concentration and temperature of contrast agent) identical to those employed clinically.

14. Quality Control In Computed Tomography

In equipment as complex as a computed tomographic unit, routine quality control procedures are essential to the maintenance of optimal image quality. This requirement is due in part to the multitude of components involved in image formation, and in part to the extensive data processing that occurs between data accumulation and production of the final image presented to the viewer for interpretation. The latter feature decreases the usefulness of the clinical image as a means of identifying deficiencies in the process of image formation, and increases the need for prospective quality control tests to ensure satisfactory images. These tests should be performed on a regular basis in time set aside for quality control measurements. Appropriate quality control tests should also be performed following major maintenance on a computed tomographic unit.

A number of authors have addressed the topic of quality control for computed tomography (CT) units (Cacak and Hendee, 1979; Weaver, 1979; Bellon *et al.,* 1979; McCullough, 1980; Bergström, 1981). The recommendations of these authors have been compiled (Cacak, 1985) into a comprehensive quality control program for CT scanners that is summarized in Appendix A. The criteria for acceptable performance described in Table A.9 should be met by any CT unit of recent vintage; many units will perform at a substantially better level.

For any particular unit, it is important to establish the level of performance during acceptance testing of the unit and then to ensure maintenance of this performance level over time by an appropriate quality control program. For CT units manufactured after 3 September 1985, the manufacturer is required to furnish specific dose information obtained by using the CT dosimetry phantom, imaging performance information, a quality assurance phantom, and representative images obtained with the phantom (FDA, 1986).

The 20-cm diameter phantom referenced in Appendix A is a hollow disk with a thickness exceeding the maximum slice thickness attainable with the CT scanner. The phantom can be filled with air or water. For measurement of effective energy and high and low contrast resolution, a number of phantoms have been described and

many are available commercially. Any of these phantoms can be used for routine quality control. Exposure measurements can be obtained with thermoluminescent dosimeters or with ionization chambers designed for use in the narrow x-ray beams employed in computed tomography (Jucius and Kambic, 1977; Shope *et al.,* 1981; Moore *et al.,* 1981). In addition to the complete dosimetry measurements made semi-annually, a more frequent dosimetric check of technique factors at one setting may be useful to veryify that a major change in exposure rate has not occurred. Inconsistencies in bed positioning and indexing are common problems with CT scanners; these problems can be identified by making several sequential measurements with the bed positioned or indexed in different directions between measurements. For a detailed description of quality control procedures for a CT scanner see Cacak (1985).

Tolerance limits for quality control tests described in Appendix A vary somewhat with the type of computed tomographic unit. The stated limits are intended as a guide to acceptable performance of a typical computed tomographic unit. The frequency of the tests recommended in Appendix A should be increased appropriately for CT units exhibiting erratic performance; similarly, appropriate quality control tests should be conducted whenever major maintenance (*e.g.,* replacement of an x-ray tube) is performed or when a major change in equipment operation (*e.g.,* introduction of a new software package) is accomplished. The following tests should be performed.

CT number

Calibration: For a unit with CT numbers expressed in Hounsfield Units, the unit should be so calibrated that air yields an average CT number of -1000 ± 3 and water yields an average CT number of 0 ± 1.5. (To be done at least monthly; more frequently if data are used quantitatively.)

Constancy: The CT number for water, and its standard deviation over a water-filled phantom, should be verified (daily).

Uniformity: In an image of the 20-cm diameter phantom filled with a uniformly attenuating medium, the mean CT number of any 100 pixels should not differ by more than 5 from the mean CT number of any other 100 pixels. Some CT units may experience difficulty in meeting this specification; for these units, a more relaxed criterion may be appropriate (Levi *et al.,* 1982). The uniformity image can be very helpful in identifying the presence of image perturbations such

as beam hardening artifacts, detection nonuniformity rings, etc. (to be done at least monthly).

Dependence on slice thickness: For the 20-cm diameter phantom filled with a homogeneous medium, the mean CT number averaged over 100 pixels at the center should agree to within ± 3 CT numbers for all section thicknesses (to be done semi-annually).

Dependence on phantom size: The CT number of water should change by less than ± 20 as the phantom diameter changes from 5 to 30 cm, provided that reconstruction techniques and beam shaping filters appropriate for the phantom size are used. (Phantoms as small as 5 cm in diameter are useful if limb studies are performed with the unit or if the unit is used for pediatric patients (to be done semi-annually).

Dependence on phantom position: The mean CT numbers should vary by less than ± 5 CT numbers if the phantom is centered in the gantry, or ± 15 CT numbers irrespective of the position of the phantom (to be done annually).

Dependence on algorithm: The mean CT number at the center of the phantom should vary by less than ± 3 CT numbers irrespective of the algorithm chosen for the reconstruction, provided that the appropriate phantom size is used for each algorithm (to be done annually).

Visual output

Hard copy output and visual display: For a standard image, the hard copy image should not differ noticeably in luminance and contrast from the image displayed on the video monitor, as determined by visual evaluation (see Section 19.3).

Low contrast resolution: For a midline exposure of 0.5 to 0.8 mC kg^{-1} (2 to 3 R), pins of 0.5 cm diameter should be visible in the image when the x-ray attenuation of the pins (intrinsic contrast) differs by 1 percent or more from that of the surrounding medium (to be done at least monthly).

High contrast resolution: Pins of 0.1-cm diameter should be visible in the image when the x-ray attenuation of the pins (intrinsic contrast) differs by 10 percent or more from that of the surrounding medium (to be done at least monthly).

Video monitor and hard copy distortion: For a series of holes positioned 1 cm apart in a high contrast test object, the holes in the video

or hard copy image should coincide with the location of the holes in the object to within ± 1 mm in the central 50 percent of the image when the image is projected to life size. In the periphery of the image, the coincidence may not satisfy the ± 1 mm specification. (To be done at least monthly; more frequently if images are used for treatment planning or for other quantitative applications.)

Table

Position indicator accuracy: Over repeated positioning of the examination table using the bed index control, the true position of the bed should agree to within ± 2 mm of the indicated position (to be done semi-annually).

Backlash: Location of the examination table should agree to within ± 1 mm when approached from opposite directions (to be done semi-annually).

Indexing accuracy: With an appropriately loaded bed, the bed should move the nominal index amount (± 0.5 mm) for each increment. This accuracy can be verified by a ruler or by a series of exposures with prepackaged film taped to the bed. When the CT unit is used to produce projection radiographs from which measurements (*e.g.*, leg length) are obtained, tests to verify the localization accuracy and the accuracy of the quantitative measurements are necessary (to be done semi-annually).

Sensitivity profile (slice width or section thickness): The section thickness should agree to within ± 1 mm of the nominal thickness for slice thicknesses between 5 and 15 mm, and to within 0.5 mm for slice thicknesses less than 5 mm, when measured at the full width at half maximum (FWHM) with a wire oriented at 45° in a test object (to be done semi-annually).

Noise characteristic: The standard deviation of CT numbers should vary approximately as $mAs^{-1/2}$ over the region where the image is dominated by quantum mottle (to be done semi-annually).

Accuracy of distance measurements (caliper accuracy): Distances measured in a CT image should agree with actual distances to within ± 1 mm (to be done annually; much more frequently if data are used quantitatively).

Patient dosimetry: Exposures should agree within ± 20 percent among measurements obtained at different times (to be done semi-annually).

Quantitative CT: The ability of quantitative CT (QCT) to provide accurate and precise data depends upon a thorough quality control program. Whether attempting to quantify the amount of calcium in a lung nodule or the mineral content in a bone, it will be necessary to scan a clinically realistic phantom containing stable samples of known mineral content on a relatively frequent basis (monthly). The variability among the measurements is not specified in this report since an extensive data base is not available.

15. Quality Control in Digital Imaging

Digital imaging, including digital subtraction angiography and digital radiography, is being used in diagnostic imaging departments. Most of these systems are based on conventional x-ray technology, *e.g.,* x-ray generators, video cameras, television monitors, and video hard copy cameras, with modifications or additional hardware providing their unique capabilities. Since digital radiography, *e.g.,* digital chest imaging, is still in its developmental stage this section includes only digital imaging as applied to digital subtraction angiography.

15.1 Digital Subtraction Angiographic Imaging

Digital subtraction angiography (DSA) imaging equipment presents problems similar to those discussed in Sections 7 and 8, but it also has some unique features which must be evaluated to ensure optimal image quality. It is important to monitor the exposures required for DSA images because it is necessary to know the exposure in order to evaluate a particular system or to compare image quality from different systems.

Two recent studies of DSA imaging in the head and neck indicate that the use of DSA reduces exposures to the patient and the staff (Pavlicek *et al.,* 1982; Plunkett *et al.,* 1985). However, the exposure reduction realized in these studies results from reduced fluoroscopic time for intravenous studies and from smaller radiation fields. In fact, most users of DSA systems are finding it necessary to use a patient entrance exposure which is comparable to that used for screen-film images in order to obtain equivalent noise levels. This should not be surprising since most x-ray images are limited by quantum mottle. Low noise levels are particularly important for studies utilizing intravenous injections of contrast media. [It may be worth evaluating image quality of DSA images with and without a grid, since elimination of the grid reduces patient exposures by a factor of

two with minimal degradation of image quality (Gray and Swee, 1982).]

Quality control checks of DSA equipment should include all of the applicable tests for general radiographic and fluoroscopic equipment described earlier. In addition, several additional checks are necessary, all requiring specialized equipment and phantoms.

A patient-equivalent phantom including simulated vessels of various sizes (*e.g.*, 1-, 2-, and 4-mm diameter), with vessels parallel and perpendicular to the video scan lines is required. The simulated vessels should be filled with iodine bound in an acrylic or similar material with concentrations of iodine representing the intravenous and intra-arterial concentrations used. In addition, the vessels may contain simulated stenoses and aneurysms. The segments containing the vessels should be removable so that they may be interchanged with similar segments containing no iodine to simulate a pre-injection image which is then subtracted from the post-injection image.

In addition to the patient-equivalent phantom, a step wedge capable of covering the image intensifier should be available to test the dynamic range of the system.

A resolution pattern (*e.g.*, one made of 0.01-mm thick lead) should be imaged with the patient-equivalent phantom (pattern lines both parallel and perpendicular to the television scan lines) and subtracted to determine the low contrast resolution of the total system.

Any instabilities in the video scan lines from one frame to the next will result in artifacts when substraction images are produced. A mesh pattern or a step wedge oriented so that the edges of the steps are at 45° to the scan lines should be imaged and subtracted to provide information concerning such artifacts.

Both phantom and image intensifier entrance exposure must be determined along with the image quality for comparison purposes. Consequently, a dosimeter that can detect and display exposure as low as 0.13 to 0.26 $\mu C\ kg^{-1}$ (0.5 to 1.0 mR) is required.

The number of variables involved make it difficult to provide quantitative data concerning the performance level of DSA equipment. The operating levels and control limits for the general radiographic and fluoroscopic tests should be the same as those for conventional systems. In the digital substraction mode of the system, the spatial and contrast resolution depend on image intensifier quality, television system band width, pixel size, etc. Many vendors state that a vessel of a specific size and with a specified iodine concentration can be visualized with their system. This type of test is not sufficient for quality control purposes since the human eye-brain can distinguish a line under extreme conditions of noise and poor focus. A more

reliable test is to determine the presence of 25, 50, and 75 percent stenoses and similar sized aneurysms.

Control limits are also difficult to establish. However, similar systems should produce images of similar quality. Typically, the 0.01-mm lead resolution pattern should indicate a vertical and horizontal resolution of at least 1.6 c/mm for a 15-cm (six-inch) intensifier and 1.2 c/mm with a 23-cm (nine-inch) intensifier for a subtracted image (using a 512 $\times$ 512 pixel array with a 525-line video system). All systems should produce images of similar quality from one check to another.

Digital subtraction systems should be evaluated at least every three months and more often for systems frequently used. It is sufficient to check the DSA portion of the system every three months, while carrying out the other checks every six months unless problems are suspected in the conventional parts of the system. Films from the hard copy camera and the visual display should be evaluated weekly, or ideally daily, with the SMPTE test pattern (see Section 19.3). The frequent checks of the films and visual display are essential due to the variability of these two elements in the imaging chain and the ease with which the brightness and contrast controls can be changed (misadjusted). The camera and visual display should be tuned to produce a film and visual image which appear nearly identical. However, slight changes in the brightness or contrast of either device can produce extreme differences in the appearance of the images.

16. Quality Control in Nuclear Medicine

16.1 Introduction

Routine monitoring of nuclear medicine instruments, using test procedures that check the quality and reproducibility of instrument performance, is an essential part of any clinical nuclear medicine program. The aim of this monitoring is to give the user confidence that the clinical data will be free of significant variations caused by fluctuations or drifts in operating characteristics of the instrument.

The following documents include more detailed descriptions of the procedures discussed in this section: WHO, 1982; FDA, 1984b; IAEA, 1984.

16.1.1 *Care and Maintenance*

Proper care will help to ensure optimal operation and usefulness of the instruments. All instruments should be maintained in a cool, clean, dry environment. Cooling fans should be checked for proper operation, and ventilation holes should be kept clear to help maintain a stable operating temperature. Instruments which draw cooling air from the back panel must be located away from walls to allow an air space for adequate ventilation. Air filters must be checked and cleaned periodically based on manufacturers recommendations and also based on the experience of the facility.

Electrical power requirements should meet instrument specifications with properly shielded lines and with protective devices such as voltage surge suppressors and regulators. For equipment fixed in location, the high voltage to the photomultiplier tubes should be kept ON (at a reduced voltage), except when the instrument will be inactive for more than two months. Some mobile cameras automatically turn off the high voltage to the photomultiplier tubes when the camera is moved.

16.1.2 *Records*

In addition to routine quality control of instruments, the maintenance of instrument logbooks is extremely important. It is usually more practical to separate and maintain these records according to the frequency of use. Calibration and inspection records along with other infrequently used records (acceptance test data, service agreements, warranty and preventive maintenance schedules) can be kept separate from those used frequently such as quality control data. The results of daily quality control tests and notations of service calls (repairs made and service personnel names), as necessary, can be kept in one book. Data and test images made immediately following repair to demonstrate successful corrective actions should be kept in the quality control logbook. Quality control test data, particularly for imaging studies, should be readily available to the nuclear medicine physician during the interpretation of studies. The instrument operator will also find it desirable to maintain at the instrument console a daily log of operating techniques or protocol used for each patient. "Daily," as used throughout this section, indicates "every day the instrument is used."

16.1.3 *Film Processing*

For quality control of film processing, refer to Section 6.

16.2 Radionuclide Calibrator

A calibrator can be used confidently to obtain correct assays of radiopharmaceuticals prior to administration to the patient. Before each daily use of the instrument, zero setting, background setting and test setting should be checked. The following documents are recommended for a detailed description of the quality control procedures outlined below for the radionuclide calibrator: NRC, 1980; ACNP, 1984.

16.2.1 *Test Precision*

Prior to daily use of the radionuclide calibrator, the precision (repeatability of response) should be checked at the settings of radionuclides to be used on that day. Reading variations should be within the manufacturer's specifications for repeatability, *i.e.*, no

TABLE 16.1—*Reference sources for radionuclide calibrators*

Source	Activity	Principal energy (MeV)[a]	Simulated radionuclide
^{57}Co	37–74 MBq[b]	0.122 (86%), 0.136 (11%)	^{99m}Tc
^{137}Cs	3.7 –7.4 MBq[b]	0.662 (85%)	^{99}Mo
^{133}Ba	1.85–3.7 MBq[b]	0.081 (32%), 0.276 (7%)	^{131}I
		0.302 (18%), 0.356 (62%)	
		0.384 (9%)	

[a]From NCRP, 1985

[b]37 MBq in the International System (SI) of units is 1 mCi.

greater than ± 2 to 5 percent for most calibrators. Variations greater than ± 5 percent from the predicted activity indicate the need for instrument repair or adjustment. A long-lived source, usually cesium-137 in a solid or gel form (see Table 16.1) is commonly used. The cesium-137 source should be checked daily at the calibrator cesium-137 setting.

16.2.2 *Relative Response to Reference Source*

It is advantageous to take readings (preferably quarterly) of the reference source(s) at settings for more commonly used radionuclides. Long-lived reference source(s), preferably having energy emission and activity ranges representative of these radionuclides (Table 16.1), are commonly used. Sources should be in solid or gel form to minimize contamination potential and inadvertent withdrawal for other uses. Within limits of the repeatability of the instrument (no greater than ± 2 to 5 percent), the readings of the source(s) from a reliable calibrator will then follow the characteristic half-life of the radionuclide(s). Values lying outside these limits indicate drifts from calibration or changes in ambient conditions. Erratic readings may indicate electronic malfunction or fluctuation of ambient radiation levels.

16.2.3 *Test for Linearity of Response*

In addition to routine monitoring of the calibrator, quarterly testing should be performed to check the calibrator for linearity as a function of activity. For example, readings are frequently inaccurate in the high megabecquerel (millicurie) range, and a correction curve should be obtained to assay high activity samples correctly, *e.g.*, $^{99}Mo - ^{99m}Tc$ generator eluates. Linearity of response over a range of clinically used activities may be verified by successive calibrator

readings of a high-activity, short-lived source such as ^{99m}Tc. Errors greater than ± 5 percent between predicted and measured activity indicate either the need for repair or adjustment of the instrument (usually battery replacement) or the need to use a correction factor for the amount of activity to be measured.

The ^{99m}Tc eluate used in the above test is for clinical use. A kit (commercially available) using different thicknesses of lead-lined tubes to simulate decay occurring from 0 through 50 hours provides a linearity test on the radionuclide calibrator quickly and accurately (Calicheck, 1984). This method results in less personnel radiation exposure and allows clinical use of the eluate. A comparison should be made between the two approaches for the specific radionuclide calibrator prior to complete conversion to use of the kit method.

16.2.4 *Test of Accuracy*

Assessment of calibrator accuracy must be made with clinically applicable standards of known activity in a standard geometry. Calibration accuracy may be verified by using radionuclide standards spanning a wide range of energy, *i.e.*, ^{57}Co, ^{133}Ba and ^{137}Cs, traceable to the primary standards of the National Bureau of Standards (NBS), and determining the present activity of each source versus the calibration setting. Calibration checks that do not agree within ± 5 percent indicate that the instrument should be repaired or adjusted (NRC, 1980). For best accuracy, the lower energy reference standards (^{99m}Tc, ^{133}Xe, ^{125}I) must be in vials with the same thickness of material as the actual samples to be measured.

Measurements of radionuclide calibrator accuracy should be obtained annually and after repair or adjustment of the calibrator.

16.2.5 *Test for Geometry Effects*

There may be significant variation in measured activity as a function of sample volume or configurations, depending on the volume and size of the radionuclide calibrator chamber. The extent of these geometry effects should be ascertained for commonly-used radionuclides and appropriate correction factors computed if variations are significant, *i.e.*, greater than ± 2 percent. Even though correction factors may be provided by the manufacturer, the accuracy of these should be checked. It should be noted that differences of 200 percent in calibrator readings between glass and plastic syringes have been observed for lower-energy radionuclides such as ^{125}I (Van Tuinen and

Kereiakes, 1981). Hence, correction factors must be established for various types of syringes. As an alternate to syringe-correction factors, the stock vial may be assayed before and after filling the syringe. The activity in the syringe is then the difference between the two readings (with a volume correction, if significant).

Geometric effects of clinically-used assay containers should be determined upon installation of the calibrator. Special precautions are required when a new radionuclide is used and, in particular, for radionuclides such as ^{125}I and ^{133}Xe where self-attenuation and attenuation by container materials may be large (Van Tuinen and Kereiakes, 1981).

16.3 Scintillation Spectrometer

16.3.1 *Quality Control Test*

Quality control procedures for NaI(Tl) scintillation spectrometers involve more quantitative tests for nonimaging users of spectrometers to evaluate performance accuracy; whereas, some qualitative tests are used to ensure performance consistency of imaging spectrometer systems. When a spectrometer is first installed and accepted, tests should be performed to evaluate variables that may influence the counting accuracy of radioactive samples (*e.g.*, volume and count-rate effects) and to establish baseline performance values for periodic testing. Frequency of quality control tests for scintillation spectrometers are given in Appendix A.

16.3.2 *60-Herz Test*

Many NaI(Tl) spectrometers (particularly older models) have a switch that disconnects the detector from the remainder of the electronics and introduces a 60 pulse/second signal into the scaler circuit. A one-minute measurement of this test input should yield 3600 ± 1 or 2 counts. If a ratemeter is used, a time constant of one second may be set and a reading obtained after four time constants. Failure to obtain 3600 counts per minute (cpm) usually implies malfunctioning scaler-timer circuits in the scaler or the tank circuit in the ratemeter.

16.3.3 *Test of Pulse Height Analyzer (PHA)*

This test is conveniently performed with a small long-lived reference source, *e.g.*, 2 to 10 kBq (0.05 to 0.3 μCi) ^{137}Cs, placed in the

sensitive area of the detector. A record of the amplifier gain or photomultiplier tube high voltage setting used to obtain the maximum count rate of the source for a specific PHA discriminator setting indicates the stability of the PHA or high voltage supply and its energy-scale calibration to radionuclide energies of the reference source. The amplifier-gain (or high-voltage) setting should remain nearly constant. A rising gain or high-voltage setting could indicate a drifting high-voltage supply, failure of the hermetic seal around the crystal, failure of the optical coupling between crystal and photomultiplier tube, or an unstable photomultiplier tube or amplifier. Fluctuating readings may indicate an unstable high-voltage supply or amplifier gain.

16.3.4 *Background Activity Check*

A one-minute measurement of background activity should be obtained for each established instrument setting routinely used, and this reading should be recorded each day the instrument is used. High readings may indicate contamination of the detector or of the environment in the vicinity of the detector, or the presence of radiation such as from an x-ray unit or a patient who has received a radionuclide. Appropriate measures (*e.g.*, decontamination or removal of the source) should be implemented to maintain background readings at a constant level.

16.3.5 *Test of Precision*

The consistency of spectrometer performance is determined by making a timed measurement of long-lived sources such as ^{137}Cs, ^{57}Co, ^{133}Ba, or ^{129}I in a reproducible geometry. A holder is useful for positioning the source in a reproducible geometry with a probe-type spectrometer.

Variations of the net count obtained each day should be less than three standard deviations of the mean (obtained initially from a series of 10 to 20 measurements of a long-lived source). If a count is observed outside these limits, the procedure should be repeated. If a second count falls outside those limits, faulty performance is indicated and instrument recalibration or servicing is recommended. Counts falling below the control limit indicate drift of the photomultiplier tube, amplifier, or voltage supply or deterioration of the crystal. Rising, or erratically high, counts indicate extraneous noise, high ambient background, or electronic failure.

16.3.6 *Chi-square Test*

To ascertain the overall ability of an instrument to process a random statistical distribution of radioactive emissions, a Chi-square test should be performed. This test involves a series of measurements (*e.g.*, 10 observations) of a long-lived source (*e.g.*, ^{137}Cs, the activity of which may be considered a constant) and comparing a computed statistical value (probability value, P) against a corresponding value for a Poisson distribution. [See NCRP Report No. 58, Second Edition (NCRP, 1985) for a discussion of necessary radioactivity counting statistics.] A value of $P = 0.5$ is ideal, and $0.1<P<0.9$ indicates acceptable performance of the instrument. For $P<0.1$, the distribution of observed counts is too broad to fit a Poisson distribution, while $P>0.9$ indicates the distribution is too narrow. If $P<0.1$ or >0.9, additional measurements should be made (*e.g.*, 20 observations). If the same result is obtained, an instrument problem is indicated. The Chi-square test should be performed quarterly and the results recorded in the quality control logbook.

16.3.7 *Test of Energy Calibration*

Calibration of the spectrometer involves establishing a relationship between the discriminator settings of the pulse height analyzer and the size of the pulses from the amplifier (*i.e.*, the energy deposited in the crystal by the gamma-rays). In this procedure, the full range of the discriminators may be calibrated to correspond to 0 to 500 keV, 0 to 1 MeV, 0 to 2 MeV, etc., depending on the radionuclides to be measured. For test purposes, the spectrometer usually is calibrated so that 1000 divisions of the lower discriminator corresponds to 0 to 1 MeV (*i.e.*, 1 keV per division).

A ^{137}Cs test source (662 keV) of appropriate activity [*e.g.*, 2 to 10 kBq (0.05 to 0.3 μ Ci)] is positioned as required for counting. The discriminators are set to encompass a narrow window from 652 to 672 divisions. Starting with a low gain setting (or photomultiplier-tube voltage if the gain is not adjustable) so that no counts are observed, the gain (or high voltage) is increased gradually until the counting rate begins to increase, reaches a maximum and then decreases. For the gain setting corresponding to the maximum counting rate, the discriminators are calibrated to correspond to 0 to 1 MeV, with the assumption that the responses of the amplifier and discriminators are linear.

If a ratemeter must be used in place of a scaler, a similar calibration procedure may be followed. Using a time constant greater than

one second, the gain is gradually adjusted until a maximum counting rate is observed over an interval equal to at least four time constants.

The calibration procedure outlined above should be repeated quarterly with the gain and high voltage settings recorded in the logbook.

16.3.8 *Test of Energy Resolution*

Energy resolution is a measure of the spread in amplitude of voltage pulses representing total absorption of the gamma rays of interest.

To determine the energy resolution of a spectrometer, a ^{137}Cs source is generally used with the spectrometer calibrated up to 1 MeV, and a series of one-minute counts are obtained for 20-keV increments (window) from 600 to 700 keV. The counting rate should be less than 10,000 cps and total counts collected in each 20 keV increment should be >10,000. From a graph of counting rate versus center of window, the point at which the counting rate is half the maximum value is determined. Energy resolution is usually stated as the full width of the photopeak (in keV) measured at half its maximum height (FWHM) and is often expressed as a percentage of the photopeak energy (% FWHM).

The measurement FWHM should be compared to the resolution stated by the manufacturer. A typical resolution is 8 to 9 percent for solid cylindrical crystals and 10 to 11 percent for well-type crystals for ^{137}Cs gamma-ray energy. If the value obtained is different from that stated by the manufacturer, the reason may be that the window width used by the manufacturer for determination of energy resolution was different from that used in this protocol. A determination of energy resolution should be repeated annually and following repair, and should be compared with the initial value.

A change in energy resolution usually indicates a defective crystal, photomultiplier tube or preamplifier assembly. Problems most frequently encountered are a cracked crystal, broken moisture seal, or varying high voltage. Service personnel should be called in to inspect the spectrometer to determine the actual cause of resolution loss.

16.3.9 *Test of Linearity*

Linearity of spectrometer describes the relationship between the size of the voltage pulse produced by total absorption of photons in the crystal and the center-of-the-window setting necessary to observe the pulse. In a linear system, a direct relationship exists between

photon energy and the center of the discriminator window needed to observe the photopeak.

To evaluate linearity, the window setting that encompasses the center of the photopeak is determined for ^{137}Cs (667 keV), ^{131}I (364 keV), and ^{99m}Tc (140 keV). A graph of the center of the window versus energy of the photopeak should yield a straight line. A nonlinear relationship (greater than ± 2 keV) may be due to unstable discriminator bias or nonlinear gain of the amplifier, or failure of the optical coupling between crystal and photomultiplier tube. Either a pulse generator or a selection of radionuclide sources may be used to determine the energy response of the spectrometer.

The test of linearity should be performed at least annually.

16.3.10 *Counting Rate Effects*

A scintillation spectrometer can accurately process a limited number of counts per minute. As the counting rate increases, counts are lost because of the finite decay time of the NaI(Tl) crystal and of pulse pile-up in the amplifier. For most spectrometers in nuclear medicine, the counting rate limit is approximately 10,000 cps.

The counting rate at which significant counts begin to be lost may be evaluated with samples of varying activity, *i.e.,* using such techniques as decay of a high activity source, dilution of a high activity liquid source, and use of paired sources. The activities should cover a factor of 100, with the largest activity yielding a counting rate in excess of 10,000 cps. Each sample is measured, and the observed counting rate is plotted as a function of relative sample activity. The linear portion of the curve determines the range of true counting rates. Counting rates not on the linear portions of the curve should be interpreted with caution. Counting rate limits for spectrometers may be set by deciding on acceptable counting losses. Spectrometers should usually be operated at counting rates less than the rate for which five percent of the true counts are lost.

16.4 Nonimaging Scintillation Systems

Tests for quality control of spectrometers are described in Section 16.3. In addition, a determination of the precision and of the effects of geometry for nonimaging scintillation systems, such as well counters and uptake probes, should be made.

The test for counting rate effects should be performed at least annually.

16.4.1 *Precision (Repeatability)*

The test of precision (repeatability) can be made by measuring a check source (cesium-137 or cobalt-57) in a fixed reproducible geometry. The geometry may be best obtained by mounting the source in a fixed position in a Lucite© holder that provides a fixed distance from the detector face.

Variations in the net counting rate obtained each day should be less than three standard deviations of the mean (obtained initially from a series of 10 to 20 measurements of the check source). For a check source such as cobalt-57, physical decay must be taken into account. For additional details, refer to Section 16.3.

16.4.2 *Test for Geometry Effects*

The observed counting rate of a sample is dependent on the volume and position of the sample in relation to the detector. To evaluate the volume dependence of a well counter, a small volume (less than 0.5 ml) containing approximately 20 kBq (0.5 μCi) of a radionuclide (*e.g.*, ^{131}I) is placed in a test tube and measured. A measurement is obtained after additional volumes are added up to a maximum volume. To minimize statistical fluctuations, a total count greater than 10,000 should be obtained for each sample. A plot of counting rate versus volume demonstrates the dependence of counting rate on sample volume.

The position of the source relative to the detector may also affect the observed counting rate. Position dependence for a well counter may be evaluated by measuring the counting rate with a small-volume sample as the sample is raised within the well. The effect illustrates the need for ensuring that samples are counted at the bottom of the well, or at least in a reproducible geometry. Position dependence for an uptake probe may be evaluated by measuring the counting rate with a small-volume sample at various distances of the sample from the face of the crystal.

16.5 Rectilinear Scanners

Rectilinear scanners continue to be useful in some clinical nuclear medicine laboratories, hence quality control procedures for these instruments are included here.

As indicated in Section 16.3, testing of the imaging spectrometer may include 60-Herz count (if available), background check, sensitivity check, and a check of pulse height analyzer calibration. In addition, the following tests for a rectilinear scanner are performed routinely (see Appendix A) to ensure that the scanner is operating consistently.

16.5.1 *Precision (Repeatability)*

The precision (repeatability) check can be made with the same check source and geometry used for the uptake probe. The check source is mounted at the focal plane of the collimator and remains at this position while performing precision checks. The gain and high-voltage settings for proper spectrometer calibration are recorded to evaluate any long-term changes. Variations of the net counting rate obtained each day should be less than three standard deviations of the mean (obtained from a series of 10 to 20 measurements of a long-lived source).

16.5.2 *Density Calibration Check*

Images produced by the rectilinear scanner usually are recorded on medical x-ray film. When the rectilinear scanner is first used, the photorecorder should be evaluated by obtaining a density calibration film. Areas of the test film that are exposed at the proper scan speed and photorecorder setting for different information densities should yield the same optical density. A flood source or emission phantom placed in the collimator focal plane, a point source taped to the crystal, or input from a controllable pulse generator instead of the detector may be used to obtain the density calibration film. If the optical densities are not within $\pm$ 0.2 (at about a density of 1), the scan speed or photorecorder setting may be incorrectly calibrated.

16.5.3 *Test of Contrast Enhancement*

The contrast enhancement settings of the photorecorder may be evaluated by obtaining images of a step wedge consisting of absorbers of varying thicknesses which provide varying count densities of up to 100 percent. Images of the wedge should be obtained without contrast enhancement and with various degrees of enhancement. These images illustrate the relationship of optical density to count

density for various enhancement settings. These check films should be identified and saved for future reference.

16.5.4 *Collimator Evaluation*

A knowledge of the properties of collimators is necessary to facilitate the choice of a correct collimator for a particular imaging study. A chart may be made describing the properties and uses of each collimator, including the following: energy range, number of holes, relative sensitivity, spatial resolution, focal length, and depth of focus. This chart may be compiled from information supplied by the manufacturer for each collimator; the chart should be kept with the collimators for easy reference.

16.5.5 *Collimator Spatial Resolution*

Position a point source of radioactivity in the focal plane at the location yielding the maximum count rate. The source is then moved along a line parallel to the face of the collimator to the location that gives half the maximum counting rate. The distance between these locations is the 50 percent response resolution distance. A knowledge of the 50 percent response is useful for comparing the relative resolution of collimators.

16.5.6 *Collimator Depth of Focus*

The depth of focus of a collimator is usually measured as the length of the 50 percent isoresponse curve. A small point source is placed in the focal plane at a location yielding the maximum number of counts, then raised toward the collimator along a line perpendicular to the collimator face until half the original counting rate is observed. This distance is noted, and the procedure is repeated with the source moved away from the collimator. The distance from the upper to the lower half maximum points is the depth of focus of the collimator.

16.6 Scintillation Cameras

As indicated in Section 16.3, daily testing of the spectrometer may include a 60-Herz count (if available), background count, and a check of the pulse height analyzer calibration. Performance checks of the

following characteristics which may cause significant degradation in the quality of scintillation camera images should be made routinely (FDA, 1976; Hine *et al.*, 1977; 1979) (see Appendix A).

Uniformity: ability of a scintigraphic instrument to provide a uniform image of a uniformly distributed radioactive source.

Spatial Linearity: ability of scintigraphic instrument to produce images of a linear array of radioactivity

Spatial Resolution: ability of a scintigraphic instrument to produce and display images, discernible as separate entities, from an array of radioactive sources. Resolution is expressed as the maximum spatial frequency (line pairs per cm or cycles per cm) which may be discerned on the image of a bar or hole phantom.

Sensitivity, Relative: ability of a scintigraphic instrument with a given collimator to detect the gamma rays emitted from a radioactive source [counts/kBq (nCi) of activity].

For those nuclear medicine laboratories having standard imaging computer capability, the following documents are also recommended: NEMA, 1986; Raff *et al.*, 1984; Adams, 1984.

In performing tests of the above characteristics, the stability of the photopeak position and the cathode-ray tube "intensity", as well as the relative sensitivity and size of the image field, are also monitored. A systematic record of these factors, when compared to previous test records, will aid in identifying changes in the quality of the test images that will require instrument servicing to maintain optimum camera performance. Any slight change in the images may be an indication of slow deterioration or maladjustment of a camera component. If changes persist, preventive maintenance is indicated even though the camera may still be clinically usable.

16.6.1 *Test for Uniformity*

The uniformity of a detector response is evaluated with a flood source or phantom placed against the collimator or detector face and imaged for at least 1 million counts. Alternatively, a small-volume source of radioactivity placed at least four field-of-view diameters from the detector face may be used provided that the collimator is removed. If an electronic iris is not available, a lead ring mask may be used to limit the field of view to that normally seen when a collimator is used.

The predominant clinical use of ^{99m}Tc, with its 140-keV gamma-

ray energy, establishes the energy range of the quality control radiation source. A number of facilities use ^{99m}Tc eluate for routine quality control testing even though its use requires daily replenishment. This inconvenience can be avoided by the use of ^{57}Co (271-day half-life) with a principal gamma-ray energy of 122 keV.

Plane radiation sources may be used in either solid form as a disc (flood source) or in liquid form contained in a large flat plastic container (flood source). Either form may be used with the collimator attached or unattached, provided that the activity is adjusted so that the count rate does not exceed 10000 cps to minimize coincidence counting loss. For uniformity, deviations from a uniform count density of less than ± 6 to 7 percent are, in general, not detected by the human eye (Cohen *et al.*, 1976). Any bright or dark areas noticed in the image require immediate corrective action.

A computer interfaced with the scintillation camera may be used also to obtain a more objective measure of field uniformity. In a program commonly used, a mean count per channel is calculated from a selected central portion of the digitized image. Then the actual value of each channel in the image is compared against limits based upon the calculated mean. A map of image points which exceed the ± 7 percent limits may then be produced. A more sophisticated program involving data smoothing and the determination of integral uniformity and differential uniformity was proposed by National Electrical Manufacturers Association (NEMA 1986). Raff *et al.* (1984) present a practical implementation of this program, whereby, integral uniformity index and differential uniformity are computed and plotted daily.

Some camera suppliers have incorporated a computer program that provides a corrected camera uniformity flood. Many cameras have uniformity correction modules that depend, at least partially, on a stored count-correction matrix. The incoming data are compared with the count correction matrix and counts are either added or subtracted from the image to compensate for nonuniformities on a basis of count density rather than count performance. Cradduck and Farrell (1984) have expressed concern over the manufacturers' specifications for these cameras and the manner in which quality control is being performed. Manufacturers who market scintillation cameras that depend on a count-correction matrix should be encouraged to quote a specification for the uniformity of their cameras without count correction in action. In addition, some users seem to believe that complete quality-control requirements are fulfilled if images are acquired after count correction. The count-correction procedure defeats the whole purpose of quality control and fails to reveal nonuniformities that may have developed. The user should collect a

quality-control flood image with the uniformity circuits first disabled and then active. Apart from the images obtained, a record of the counting rate (or time required for a set number of total counts) under these two conditions will provide a measure of the percentage of counts either skimmed or added and will indicate possible uniformity problems.

A nonuniformity due to the photographic system, such as an accumulation of dirt or dust on the oscilloscope face, may be distinguished from one due to the detector system by taking a repeat field-flood image with the orientation control rotated to a 90° position. If the location of the anomaly appears to shift, the detector system is faulty. The most frequent cause is a mistuned photomultiplier tube. For bright areas of nonuniformity, diffuse contamination may be the cause.

16.6.2 *Test for Spatial Linearity and Resolution*

Spatial linearity and resolution may be evaluated simultaneously by interposing a bar or hole phantom between the radiation source and detector, with the phantom placed directly against the collimator or detector face and the bars or holes aligned with the X and/or Y axis. At least 1 million counts should be collected. The best interpretation of spatial linearity is obtained with the bar, or hole, phantom which uniformly spans the entire field of view. An image of the hole phantom provides a way to monitor instrument performance simultaneously in the X and Y direction; whereas, separate images of the bar phantom oriented in the X and Y directions are needed. A disparity or a lack of symmetry in the number of bars or holes that can be observed visually in the X and Y directions indicates distortion of image size.

A more sophisticated approach, for laboratories with standard imaging computer capability, is provided by NEMA (1986) and Raff *et al.* (1984). Images of an orthogonal-hole and/or a PLES (parallel line equal spacing) phantom are acquired as 256 × 256 byte mode matrices (or as 512 × 512 matrix if provided by computer). Absolute spatial linearity (maximum displacement of an imaged line source for an ideal "grid") and intrinsic spatial differential linearity (standard deviation of all the peak separations) are calculated in both the X and Y directions. An "ideal" grid is then defined (Raff *et al.*, 1984). The "ideal" grids are overlaid on the line bar patterns obtained, 3-cm horizontal rows are summed and peaks determined, and the maximum displacement of any peak location in the phantom image from the ideal grid is calculated. The differential spatial linearity is

also determined from the standard deviation of all the peak separations from each other. All results are given in millimeters.

Spatial resolution is best evaluated by the use of a bar or hole phantom, or phantom segment, which most closely matches the optimal spatial resolution of the particular scintillation camera. A loss of resolution is indicated by a decrease in sharpness of the bar or hole-pattern image. The definition of holes in the hole phantom image also provides a subjective evaluation of resolution.

The resolution frequently is reduced at the periphery of the field of view. A field nonuniformity will result in a mottled appearance for the bar pattern. Localized disturbances or occasional random breaks of bar pattern image may not be serious. Sharp repetitive breaks or a complete loss of bar-image lines repeated over the field of view may arise from a moiré interaction between the bar width and the spacing of the collimator holes. In such cases the test should be repeated after a slight rotation of the phantom or with a phantom having a different hole spacing. The mottled appearance of the moiré pattern should either shift or disappear.

In most facilities, resolution is evaluated weekly or even less frequently by visual inspection of images of the bar phantom used. More stringent resolution measurements (NEMA, 1986) involve quantification of the full width at half maximum (FWHM) and full width at tenth maximum (FWTM) of the line spread functions obtained. Each line spread function in the horizontal slice profile is fitted to a Gaussian function by a least squares technique and the FWHM and FWTM reported. The system's FWHM is averaged for the X and Y directions (and the same for the FWTM) and results are reported in mm. A more detailed practical implementation of this approach is available (Raff *et al.*, 1984).

In addition, system spatial resolution (with and without scatter) of a scintillation camera and collimator may be performed to characterize the ability to determine accurately the original location of a gamma ray on a X-Y plane. Technetium-99m line sources (1 mm inside diameter tubing and 50 mm between tubes) are placed about 100 mm from the collimator face. A 20 percent window is used with counting rates less than 10000 cps. Total counts in the peak channel should be $\geq$ 10000. Measurements are then repeated with scatter material (either acrylic or pressed wood)—50-cm thick about line sources and 100-mm thick between line sources and collimator face. Again, the total counts should be $\geq$ 10000 in the peak channel. From count profile data, obtain the peak-to-peak distance (to calibrate mm/channel) and also report the FWHM average and FWTM average. Compare the results with the values obtained at acceptance testing of the scintillation camera.

16.6.3 *Relative Sensitivity*

Relative sensitivity is monitored by observing the recording of elapsed time when measuring the flood source. When the activity used each day is variable, such as ^{99m}Tc in a flood phantom or a small volume source, the ratio of the counts per kBq (μCi) should be computed. Successive determinations of the relative sensitivity varying by more than ± 10 percent indicate system instability.

For a scintillation camera with a uniformity correction system, the uniformity test should be performed on both the corrected and uncorrected images, noting the times required to collect the same total number of counts. The time required for the corrected flood image, compared with that required for the uncorrected flood image, will depend on the uniformity correction technique, less for the count-addition technique, more for the count-subtraction technique and equal for the unblank modulation technique. For the first two cases the difference in times should not exceed 20 percent (NEMA, 1986).

16.6.4 *Counting Rate Characteristics*

Counting rate performance characterizes a scintillation camera's ability to function accurately at counting rates close to the maximum rate of camera operation. By using different source strengths, plot observed counting rate versus true counting rate (varying source strength). Report input counting rate for a 20 percent count loss. The test also provides a calibration curve which can be used for dead-time correction of dynamic studies. The test should be performed any time major repairs or modifications are performed and any time the routine dead-time monitoring test indicates a significant change (10 percent) in dead-time.

16.6.5 *Energy Resolution*

Energy resolution of a scintillation camera characterizes its ability to identify accurately the photopeak events, *i.e.*, its ability to distinguish between primary gamma events and scattered events. This test can be performed by placing a ^{99m}Tc point source at approximately 150 cm from the scintillation camera crystal without collimator or phantom. The counting rate should be less than 10000 cps and total counts collected in the peak channel should be ≥ 10000. There should be 50 channels per FWHM if possible (although 10 channels per FWHM are satisfactory). Report the FWHM in percent

of energy (NEMA, 1986). Compare the results with the values obtained at acceptance testing of the scintillation camera.

16.7 Imaging Accessories

The performance of accessory-imaging and data-recording devices should be routinely evaluated for changes weekly and whenever repairs are made.

16.7.1 *Multiformat Camera*

For a multiformatting camera, transmission images of a bar or hole phantom should be obtained for all formats. A comparison of the various format images with each other and with the image simultaneously obtained from the scintillation camera provides a means of evaluating changes in image quality for multiformat devices. Video imagers which include a computer generated test pattern are also recommended. See Section 19 for additional material on multiformat cameras.

16.8 Single Photon Emission Computed Tomography System (SPECT)

While quality control procedures are well established for conventional camera devices, special considerations apply to rotating gamma camera (SPECT) systems to ensure images of optimal quality. SPECT requires precise technique, attention to detail, and almost flawless instrument performance. Such performance can only be obtained by a careful and rigorous quality control regimen.

Scintillation cameras (with rotation capability) still must undergo the quality control procedures (including tests of linearity, resolving power, image accessories, relative sensitivity, counting rate characteristics, energy resolution and spatial resolution) discussed in the section on scintillation cameras.

In addition, there are several specific areas that must be addressed in an adequate quality control program for a rotating camera (see Appendix A). These include: (a) determination of field uniformity variations and their correction by computer, (b) determination of the center of rotation, (c) pixel size determination, (d) camera-table alignment, and (e) spatial resolution (planar and transaxial). The

following publications provide more detailed descriptions of these procedures: (Areeda *et al.*, 1983; King *et al.*, 1983; Leach *et al.*, 1984; NEMA, 1986).

16.8.1 *Field Uniformity*

Assuring the uniformity of camera response is probably the single most important element in performing artifact-free tomography. The reconstruction algorithm used in tomography tends to amplify greatly the effects of nonuniformities present in the camera's field response. For example, a camera uniformity of ±2 percent could, depending on the position and type of nonuniformity, generate errors in the tomogram of up to ± 20 percent (King *et al.*, 1983). The camera uniformity should be controlled to within ± 1 percent. No currently manufactured camera can achieve such intrinsic uniformity, and it is also possible to introduce additional nonuniformities between the camera and the computer. For this reason, an externally imposed correction for detector nonuniformity is necessary for tomography, and this correction is performed in the computer. A single multiplicative flood correction appears to work well for this purpose. If a computer-imposed flood correction is to provide uniformity of ± 1 percent or better, the random variation in the flood used to generate the computer correction factors must be less than ±1 percent. In general, for SPECT systems using a wide-field-of-view detector, to derive correction factors for daily quality control flood, a 30 million count flood image must be acquired weekly (if a matrix of 128 × 128 is used for SPECT acquisition, approximately 100 million counts are recommended). These images are used to create correction matrices (applied to all images during reconstruction), but are also used to monitor camera uniformity and changes over time. Integral uniformity (calculated from the maximum and minimum value in the field of view) and differential uniformity (representing the worst-case rate of change of the flood field over a distance of 5 pixels) are determined over the central and the usable field of view. These values are recorded and used to monitor uniformity changes over time. Daily quality control must consist of 3 million count flood images corrected using the factors derived as above. The comments set out in Section 16.6.1 concerning proper quality control procedure for computer corrected uniformity become of increasing significance in SPECT systems. If numerical data are to be extracted from images, it is even more important that the effects of count skimming or count addition should not modify those numerical results (Cradduck and Farrell, 1984).

Gamma cameras are suspect for change in uniformity during rota-

tion. Tests to determine a change in uniformity during rotation should be performed quarterly or if nonuniformity is suspected. The following quality control check should be performed: acquire 30 million count correction factors at 0° and evaluate as above; next acquire 3 million count quality control floods at 0°, 90°, and 270°, and correct all counts with the correction factors acquired at 0°.

In addition, care should be taken to ensure that the flood source itself is adequately flat and uniform. Some commercial plastic cobalt flood sources are typically guaranteed only to a uniformity of ± 4 percent, and many commercially available liquid-filled flood sources tend to bulge noticeably toward the center when they are filled. Cobalt flood sources with a ± 1 percent uniformity should be specified for SPECT use.

16.8.2 *Center-of-Rotation Determination*

The location of the center of rotation of the camera as seen by the computer is a critical factor in proper tomographic reconstruction. This provides a normalizing point that allows all of the individual projection images to be properly aligned for back projection during the reconstruction process. The apparent center of rotation may vary from the mechanical axis due to variations in camera alignment, analog-digital-converter gain and offset, and other effects. The center of rotation should be determined weekly and certainly always after any electronic adjustment to the camera and/or computer. This procedure, along with the field-flood correction described above, is most conveniently accomplished if suitable software is provided by the commercial supplier.

Some SPECT cameras have a calibration program that supplies quality control data relating to the variation of the center of rotation (XCR) and the deviation in the Y direction (YC) of a point versus angular position. An acceptable camera should have variations of XCR and YC not greater than ± 0.5 pixels (± 2 mm). Calibrations, which should be performed weekly and whenever the camera field size changes, may also be required with different collimators.

16.8.3 *Pixel Sizing*

The effective size of the individual pixels in the reconstruction tomograms must be known accurately in terms of "real world" dimensions. The proper functioning of most attenuation correction algorithms requires that projection path lengths through the body be

known. In addition, accurate image scaling for size and volume determination requires a knowledge of pixel size. The calibration value for individual pixel size is subject to variation from many of the same factors that affect the apparent center of rotation. This calibration should be done on the same schedule (weekly) as the center-of-rotation determination. This test is aided considerably by the availability of special calibration software provided by the commercial supplier.

16.8.4 *Camera Axis of Rotation-Plane Alignment*

The axis of rotation of the camera and the plane of the camera's crystal must be parallel during tomographic data acquisition in order to ensure best tomographic image separation and resolution. The gantry design of several commercial SPECT systems causes the angle of the crystal plane to vary as a function of the radius of rotation. In addition, this angle can be changed manually in all systems. Great care must be taken during patient setup to ensure that this alignment is restored (within $\pm$ 2 mm) after the patient has been positioned in the system. This is an area in which stringent adherence to technique must be followed and is also an area in which small convenience features on the camera can markedly improve the efficiency with which a study can be conducted. Again, specific inquiry should be made as to how this alignment is established and maintained.

16.8.5 *Spatial Resolution*

Measurements of spatial resolution (transaxial) of rotating gamma-camera systems are a valuable indication of physical performance of the system. These measurements can be carried out under good experimental conditions; *i.e.*, with a high resolution collimator, a small detector sampling interval, a small radius of rotation, a small angular sampling interval, a large number of collected photons per image, and a frequency window in the reconstruction algorithm which does not markedly smooth the data. It is customary to provide a scattering/attenuating medium in which small diameter line sources are embedded to obtain the reconstructed line spread function (LSF). These LSF values should be compared with the LSF value obtained at time of acceptance of the system (manufacturers' published LSF specifications are usually based on measurements of this type).

Although these measurements determine the physical performance of the tomographic imaging device, they are not representa-

tive of the resolution obtained when imaging patients under routine clinical conditions. Under these circumstances, projection views are often only sampled, and, on a 64 × 64 matrix (this may be a fixed parameter in a commercial system), at about 64 angular intervals, in order to minimize reconstruction time and computer storage/memory requirements. A high- or medium-sensitivity collimator may be used, together with a large radius of rotation to accommodate the patient, and a frequency window in the reconstruction algorithm providing substantial smoothing, to reduce reconstructed image noise. All of these factors will combine to reduce the resolution in the clinical image, and it is therefore important to present measurements of the spatial resolution under the conditions used with patients to indicate the resolution that may be achieved in routine imaging procedures. These measurements should be performed in addition to those made under ideal conditions.

In addition to providing spatial resolution characteristics of the SPECT system, these measurements may indicate artifacts introduced by the system when used under conditions simulating the clinical situation. The user should be alert to this possibility of artifacts and should make appropriate measurements (as indicated) or other suggested measurements for transaxial resolution (Budinger *et al.,* 1977; Jaszcak *et al.,* 1979; Jarritt *et al.,* 1982; Webb *et al.,* 1983) and for planar resolution (NEMA, 1986). In the rapidly changing field of SPECT, the user should keep abreast of the current literature.

16.8.6 *Phantoms*

Commercially available phantoms are required for certain tests. These include: (1) a phantom for testing uniformity, *e.g.,* a cylindrical uniformly distributed source; (2) a phantom for testing longitudinal resolution; *e.g.,* a point source immersed in a scattering medium; and (3) a phantom for the total performance test, which should consist of a cylinder with an outer shell containing a uniformly distributed source of low-activity concentration, and inside the cylindrical source, "hot" and "cold" rods placed asymmetrically with their long axes parallel to the long axis of the phantom.

16.8.7 *Testing of the Camera-Computer System*

Testing of the camera-computer system requires the following procedure: (1) verify that a point source on the rotational axis is

always positioned in the center of a specific pixel; (2) verify that the size of the object is consistent with the reconstruction area; and (3) verify that no pixel count overflow occurs during data acquisition. This test should be performed annually.

16.9 Xenon Trapping Systems

Disposal of clinically used xenon-133 may be accomplished by trapping onto charcoal or other absorbing medium. Xenon trapping systems are commercially available. Filters used in these systems (containing ^{133}Xe) are then stored for decay.

An area of concern with these trapping systems is that charcoal is not 100 percent efficient for trapping ^{133}Xe. Therefore, a quality control procedure is required to check the exhaust of the trapping system periodically for possible leakage.

Commercial instruments are available for monitoring the effluent of the gas trapping system. These instruments are capable of providing total effluent [in units of DAC-hours (derived air concentration-hours)] and effluent exposure rate (in fractions of DAC). The permissible ^{133}Xe exposure is 40 DAC-hours per week. Some instruments provide a visual or audio alarm to indicate that the permissible level has been reached. These commercial systems have advantages in that they may also be used as room air monitors for ^{133}Xe.

Nuclear medicine laboratories may devise simple air collecting systems such as a relatively large plastic or rubber bag for trapping xenon. Activity collected in these bags may be assessed using a fixed geometry with a detector system such as a gamma camera, provided that the arrangement has been calibrated using known amounts of ^{133}Xe. Grossman *et al.,* (1982) proposed a simple air sampler for monitoring the efficiency of ^{133}Xe charcoal traps. This sampler consists of a three liter plastic bottle and one-way valves available from a disposable ventilation kit. The trap exhaust is pumped through the sampler for a few minutes; then the sampler is removed and evaluated with a survey meter. After calibration with known amounts of ^{133}Xe, the observed counting rate or radiation level provides a measurement of ^{133}Xe concentration in the trap exhaust. Trapping efficiency can then be estimated. The routine quality control procedure consists of comparing the observed survey instrument reading with a decision point or action level reading. These types of samplers provide a viable economical alternative to a commercial air monitor in situations where room air monitoring is unnecessary or can be accomplished by other means.

16.10 Survey Meters

Quality assurance of survey instruments should involve checks of calibration and constancy of operation (NRC, 1980; FDA, 1984b).

16.10.1 *Calibration*

An adequate calibration of survey instruments cannot be performed with built-in check sources or with electronic components that do not involve a source of radiation; calibration shall be performed with radionuclide sources. Sources shall be approximate point sources, and their source activity or exposure rates at a given distance shall be traceable to standard sources certified within ± 5 percent accuracy by U.S. National Bureau of Standards (NBS)[5] calibration. Sources of ^{137}Cs, ^{226}Ra, and ^{60}Co are appropriate for use in calibrations. The activity of the standard should be sufficient to calibrate the survey meter on each scale to be used. Each scale of the instrument shall be calibrated at two points located at approximately ⅓ and ⅔ of full scale. Readings within ± 20 percent are considered acceptable if a calibration chart, graph, or response factor is prepared, attached to the instrument, and used to interpret meter readings to within 10 percent for radiation protection purposes.

The instrument must be calibrated at lower energies, if its response is energy dependent, and if the instrument is to be used for quantitative measurements in the ^{133}Xe and ^{99m}Tc energy ranges. These calibrations may be performed, as indicated above, with calibration standards of radionuclides at or near the desired energies; or as a relative intercomparison with an energy-dependent instrument and uncalibrated radionuclide. Alternatively, the manufacturer's energy response curve(s) may be used to correct instrument readings appropriately when lower energy radiation is monitored.

16.10.2 *Constancy*

A reference check source of long half-life, *e.g.*, ^{137}Cs or ^{210}Pb(Ra D) and ^{210}Bi (Ra E) shall also be evaluated at the time of the calibration or as soon as the instrument is received from a calibration laboratory. The instrument readings shall be evaluated with the check source placed in a specific geometry relative to the detector. For convenience

[5]Name changed to National Institute of Standards and Technology (NIST) as of 23 August 1988 by the provisions of the Omnibus Trade and Competitiveness Act.

it is preferable for the check source to be fixed to the instrument. This reference check source should be evaluated before each use, after each maintenance and/or battery change, and at least quarterly.

Information about the technique to be used and the readings to be observed for the constancy check should be attached to the side of the instrument. An example of the information to be contained is given below:

SURVEY METER
CONSTANCY CHECK
source—*left* side
window—*side*
window—*open*
× 10 range
reading _____ mR/h

If any reading with the specific geometry is not within ± 20 percent of the reading measured immediately after calibration, the instrument should be recalibrated.

17. Diagnostic Ultrasound Quality Control

A basic quality control program for diagnostic ultrasound scanners should include routine measurements of the geometric accuracy of the instrument, tests of the maximum sensitivity of the scanner and evaluation of the fidelity of hard copy records. These measurements and tests can be carried out for most instruments by clinical personnel using simple test objects and phantoms. These are described under "Basic Performance Tests" below.

Higher level performance measurements of ultrasound scanners are those which are believed to characterize more completely the imaging capabilities of a system, but in general require more exacting measurement techniques than first level tests. These include measurements of the spatial resolution of the system, determination of the image uniformity for array transducer assemblies and basic characterization of the gray scale transfer properties of the instrument. These tests are also valuable for intercomparison of systems, writing purchase specifications and acceptance testing.

17.1 Basic Performance Tests of Pulse-Echo Scanners

17.1.1 *Geometric Accuracy*

17.1.1.1 *Phantoms and Test Objects.* Ultrasound B-mode images can be used to make reliable measurements of organ dimensions *in vivo*. Instruments used for such measurements should be independently tested to verify measurement accuracy.

Factors related to geometric accuracy include depth calibration accuracy, accuracy of the digital caliper readout (in the horizontal and the vertical directions on the image), compound scan registration accuracy, image distortion and externally referenced position registration accuracy.

These can be assessed using the AIUM Standard 100 test Object (AIUM, 1974) and any tissue-mimicking phantom that has a suitable arrangement of line reflectors (Carson and Zagzebski 1981; Banjavic,

1983). The speed of sound in the test object or phantom medium should be 1540 m/s ± 10 m/s; the distance between reflectors should be specified to within ± 1 percent. Both a column of reflectors and a row perpendicular to this column must be available.

17.1.1.2 *Depth Calibration Accuracy.* Depth calibration accuracy refers to the accuracy of distance measurements made from a B-mode image along the direction of one of the acoustic lines forming that image. It can also refer to reflector distance measurements made from an A-mode or an M-mode display. During clinical scans such measurements usually are done with electronically generated depth markers appearing on the display; alternatively they are carried out using "digital calipers" when provided on the instrument.

Depth calibration accuracy is assessed from the B-mode image of a column of reflectors in the test object or phantom (Carson and Zagzebski, 1981; Banjavic, 1983; Zagzebski, 1983). Distances between reflectors, measured with depth markers on the B-mode image, should agree with the actual distance between reflectors in the phantom to within ± 1.5 percent. Measurements made with digital calipers should agree with the actual reflector spacing to within the same tolerance. The test for depth calibration accuracy should be performed at least monthly.

17.1.1.3 *Horizontal Measurement Accuracy.* Distance measurements made along other directions in the image, for example, along a line perpendicular to the central acoustic line in the image, are usually less accurate than those made directly along an acoustic line. One reason for this is that there are greater uncertainties in reflector locations because of transducer beam-width effects. Another reason is that errors in the reflector position computation circuitry of an instrument may contribute to the uncertainty. Such errors are usually greater than those associated with depth calibration.

Routine performance checks of ultrasound scanners should include a test of the horizontal measurement accuracy (Carson and Dubuque, 1979; FDA, 1980; Goldstein, 1980a; 1980b; Zagzebski, 1983; Banjavic, 1983). Distances between reflectors measured on an image should agree with the actual distance to within ± 3 percent. This test should be performed at least monthly.

17.1.1.4 *Compound Scan Registration Accuracy.* Compound scan registration accuracy refers to the precision with which the position of a point target is registered on a B-mode display when the target is scanned from different directions. This parameter is relevant when using manual scanners and those automated scanners for which a point reflector can be viewed from different directions during a single

scan. Scan registration errors can lead to uncertainties in determining reflector locations; they also degrade the spatial resolution in a B-mode image.

Compound scan registration accuracy may be measured using a special-purpose arm attached to the scan arm (Hall and Fleming, 1975). More commonly, it is measured from images of reflectors in a test object or phantom (Carson and Dubuque, 1979; Goldstein, 1980a; 1980b; Zagzebski, 1983; Banjavic, 1983).

For systems in perfect registration, separate B-mode images of a point target should form an asterisk when the target is scanned from different orientations. In practice, there may be some separation in the displayed positions of a reflector. The maximum acceptable separation is 5 mm between the imaged position of a reflector at a depth of 10 cm when it is scanned from different orientations over a 90° arc. This test should be performed at least quarterly.

Attention should be paid to possible scan registration errors for real-time scanners as well. These could be caused by poor calibration of echo position computation circuitry and uncompensated refraction errors in mechanical scanners. The refraction errors referred to are those that would occur if the speed of sound of the liquid coupling medium within the mechanical scanner transducer assembly is different from that of tissue; compensation for such errors can be made in the image memory or image display section of the instrument. The most straightforward test for these registration errors is to scan an interface or a row of reflectors situated along a straight line within a test object, where the line is perpendicular to the central acoustic beam forming the image. The displayed image should also form a straight line. The registration errors may also be detected in assessments of digital caliper readout accuracy in the horizontal direction on the image.

17.1.1.5 *Externally Referenced Measurement Accuracy.* Ultrasound scanners frequently are used to localize and position biopsy needles. This is done by viewing the needle on a B-mode image as it is inserted or by mounting the needle onto an external jig. The external jig is provided with a readout of the needle-tip depth and orientation. The accuracy with which the needle tip may be directed to a specified spot seen on the B-mode image should be determined just before using the instrument for localizations. This should also be tested at least annually to ensure reliable needle tip localization (AIUM/NEMA, 1985).

Some instruments are used in applications where absolute distance measurements are needed with respect to an external reference on the patient. An example is in radiation therapy port setups, where

the depth of a reflector or an interface must be measured with respect to the skin surface. On some scanners a portion of the top of the field is not displayed on the image, or the positions of superficial reflectors are significantly distorted on an image. The magnitude of this error may be determined by scanning a test object or phantom having a rigid surface, below which reflectors are located at known distances. The error or image distortion depends on the scanning mechanism and on display factors inherent in the instrument design. Users should be aware of the magnitude of the error so that compensation can be made if necessary. One means of reducing the effect of this error is to scan with an acoustic offset between the transducer assembly and the skin surface.

17.1.2 *System Sensitivity*

17.1.2.1 *Sensitivity and Maximum Depth Visualization* The "maximum system sensitivity" refers to the weakest echo signal which an instrument is capable of detecting and displaying at a satisfactory level above noise. It is a function of the transducer assembly and associated cables, the transducer driving circuitry, and the sensitivity and signal-to-noise characteristics of the receiver. The maximum sensitivity may vary over a period of time in a given system due to changes in the instrument or in the ambient electrical noise level.

In clinical scanning the system sensitivity is most closely associated with the maximum depth of visualization of echo signals from organ parenchyma. If the system sensitivity varies, this may be detected clinically by a noticeable decrease in the depth of visualization, especially on larger patients. However, because of variability among patients, it is sometimes difficult to distinguish whether inadequate penetration is due to a fault in the instrument or is merely a patient-related problem.

Absolute measurements of the sensitivity and noise level of an ultrasound scanner must be made with respect to the echo signal from a known reflector. The American Institute of Ultrasound in Medicine specifies a perfectly reflecting planar interface in a water medium as a standard (AIUM, 1973). In a typical ultrasound scanner the maximum sensitivity may be sufficient to detect echo signals weaker than 125 dB below the echo from a perfect reflector. Therefore, a measurement of the absolute sensitivity of an instrument requires exacting techniques, sometimes involving insertion of external attenuators in the electrical circuit between the transducer and receiver (Carson and Zagzebski, 1981).

17.1.2.2 *Routine Sensitivity Checks.* For routine quality assurance it is sufficient to detect variations in the system sensitivity, without the exacting techniques required for absolute measurements of sensitivity. One method used to detect such variations over time is monitoring the system gain setting required to observe an echo signal from a specified reflector (Carson and Dubuque, 1979). Possible reflectors include one of the rods in the AIUM Standard 100 mm test object (AIUM, 1974) or the surface of a solid plastic block (Carson and Dubuque, 1979; Banjavic, 1983).

The most common approach used to detect changes in system sensitivity is to monitor the maximum depth of visualization of volumetric scatterers from a tissue-mimicking phantom (Zagzebski and Madsen, 1983; Banjavic, 1983; Hendee *et al.,* 1985). An advantage of this approach is that it tests the scanner under conditions at which the sensitivity of the instrument is challenged; *i.e.,* the system sensitivity controls are at maximum output power and gain settings.

Any tissue-mimicking phantom that provides diffuse scatterers within an attenuating medium (echo signal levels from the phantom are in the range of echo amplitudes obtained clinically) is useable for testing maximum depth of visualization. Typical phantom characteristics for carrying out this test include a speed of sound of 1540 $\pm$ 10 m/s, attenuation coefficient slope in the range of 0.4 to 0.8 dB $cm^{-1}\,MHz^{-1}$, and backscatter level of $1 \times 10^{-3}\,cm^{-1}\,ster^{-1}$ at 2 MHz.

To determine the maximum depth of visualization, the tissue-mimicking phantom is scanned with instrument sensitivity controls adjusted to provide a uniform texture pattern on the image for as large a range (depth) as possible. If the phantom has sufficient dimensions, the texture will gradually fade out with increasing depth or become mixed with electrical noise. The maximum visualization depth is estimated as the greatest depth at which a real or imaginary 1-cm diameter scatter free cylinder or sphere could be distinguished on the image. The maximum depth of visualization should not vary by more than $\pm$ 1 cm from one test to the next. This test should be performed at least monthly.

There are no standards which specify the properties for diagnostic ultrasound phantoms. Therefore, results obtained with different phantoms are not easily comparable, nor is the maximum visualization depth in any one phantom easily equated with expected visualization depth in a patient. However, tests of maximum visualization depth can be used for intercomparisons of the sensitivity of different scanners if the same phantom or phantoms of the same model are used.

17.1.3 *Image Uniformity*

When a macroscopically homogeneous tissue-mimicking phantom is imaged with an ultrasound scanner, it should be possible to adjust sensitivity controls on the instrument so that the average brightness on the image is uniform over the useful range of the transducer assembly. Nonuniformities that are sometimes seen on B-mode images include distinct vertically or horizontally oriented boundaries separating regions of different brightness or gradual changes in brightness with depth, which cannot be corrected by adjustment of gain controls. Some possible sources of these image nonuniformities include the following:

1. Variations in output or sensitivity of one or more channels of multi-element array transducer systems;
2. Inadequate compensation of echo signal amplitude changes with range (or depth) for dynamically focused array transducer systems;
3. Poor compensation in the instrument for the increased line density at the apex of images produced by sector scanners.

During quality control testing visible nonuniformities on the image of a tissue-mimicking phantom should be noted. Objective methods and criteria for testing image uniformity should be established, *i.e.*, by computer analysis of digitized images or use of specular reflectors along with calibrated gain controls, as has been done for linear arrays (Banjavic, 1983).

17.1.4 *Hard Copy Recording*

A frequent source of degradation of image quality on ultrasound scans is inadequate image photography. This may be caused by poor setup of the image exposure characteristics or inadequate processor control. It also may be caused by variations in the contrast or brightness settings of the image viewing monitor, resulting in poor matching with the monitor from which hard copy images are photographed.

Procedures described in Section 19 for setting brightness and contrast controls of the viewing and hard copy camera video monitors should be followed for setting up monitors on ultrasound scanners. In addition it is necessary to ensure that procedures are established for film processor quality control. These are described in Section 6. When gray scale reproduction is adequate, echo signal variations over the entire displayed dynamic range should be encoded in image gray level variations. This means that differences in image bright-

ness due to changes in large amplitude echo signals are visualized on the image at the same time that weak echo signals, for example from parenchymal scatterers, are successfully recorded.

Assessment of the hard copy image of the system can be carried out using day-to-day clinical images, along with the gray bar pattern generated by the scanner (Banjavic, 1983). Better standardization from one test to another may be achieved if images obtained by scanning a tissue-mimicking phantom are used rather than clinical images. The phantom provides weak "texture" echo signals that may be lost from the image when settings are inadequate. The gray bar pattern may be used to represent large amplitude echo signals (Carson and Zagzebski, 1981; Zagzebski, 1983; Banjavic, 1983). During routine tests it is sufficient to record whether any variations occur in gray bar levels corresponding to large amplitude echoes and whether any weak echo signals corresponding to weak parenchymal scatterers are lost on the image.

17.2 Higher Level Performance Tests

Additional performance tests of ultrasound scanners include measurements of the spatial resolution of pulse-echo instruments and quantitative assessment of gray scale display properties. It is believed that differences in clinical imaging capabilities are often related to the performance variables listed in this group. These variables can be specified and measured following exacting and detailed measurement procedures (Carson and Zagzebski, 1981). However, adequate measurement techniques that would permit routine quantitative assessment are not available.

17.2.1 *Spatial Resolution*

Spatial resolution may be defined as the minimum separation between two point reflectors or two scattering volumes for which separate registrations from these reflectors can be distinguished on the display. It is customary to divide spatial resolution into axial resolution, lateral resolution and, for transducer assemblies whose sound beams are not axially symmetric, elevational resolution (Figure 17.1). The elevational resolution is related to "slice thickness" of cross-sectional images. Lateral resolution and elevational resolution are functions of the transmitting and receiving "directivity patterns" of the transducer, while axial resolution is closely related

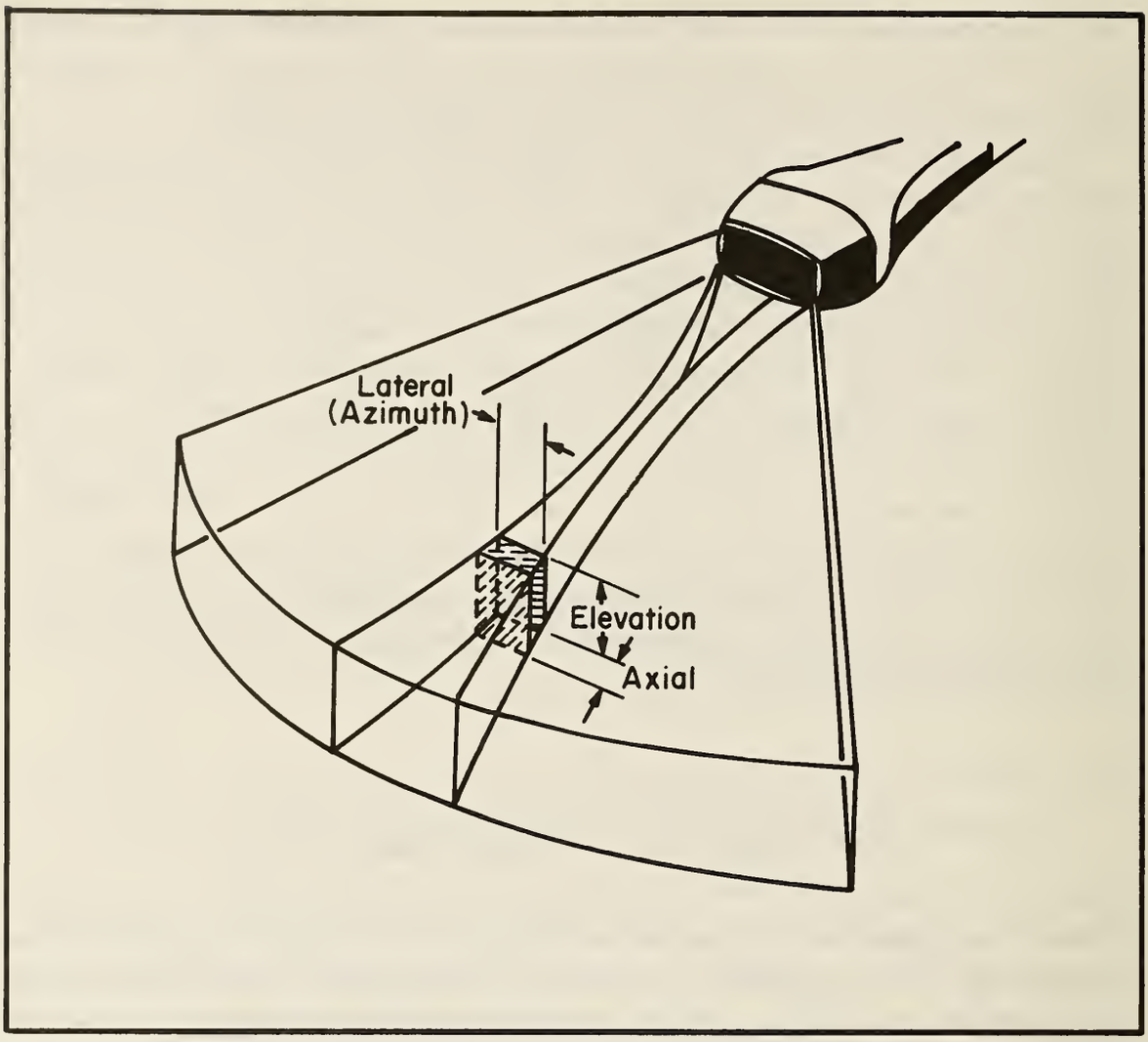

Fig. 17.1 The "resolution cell" for an ultrasound sector scanner. A scan is done by sweeping pulsed sound beams across the sector-shaped region while echoes are detected and displayed. Resolution is subdivided into lateral (or azimuthal), axial and elevational. Lateral and axial resolution are measured in the scanning plane. Elevational resolution is related to the slice thickness of the scanning plane.

to the length of time the transducer "rings" following each excitation pulse.

Quantitative assessments of system resolution are recommended during acceptance tests of scanners (Carson and Zagzebski, 1981; AIUM/NEMA, 1985; Hendee *et al.,* 1985). Periodic checks, at least annually, of spatial resolution are useful to ensure consistent system performance. Measured results will depend on the echo signal amplitude from the reflector(s) of concern. Consequently, to generate meaningful results it is necessary to standardize the system sensitivity control settings (*i.e.,* combination of acoustic output power and receiver gain) when displaying an image from the reflector. This is discussed further below.

Lateral resolution of a B-mode imaging system is most closely associated with the width of an image of a point reflector. To stan-

dardize the sensitivity control settings of a scanner during measurements such "pulse echo response widths" are measured at sensitivities referenced to the "display threshold" for the reflector (Zagzebski, 1980; Carson and Zagzebski, 1981; Banjavic, 1983). (Display threshold refers to an echo that is just barely perceptible on the image.) It is recommended that pulse echo response widths be determined at sensitivity settings of 6 dB, 12 dB, 20 dB and, if possible, 40 dB above the display threshold.

Note that these measurements require a sensitivity control that is calibrated in decibels; if none is available on the instrument, the user must provide the calibration.

Lateral resolution tests should also include measurements to determine the level of side lobes and "clutter" in array transducer assemblies. Clutter refers to spurious echoes originating from reflectors that are outside of the main beam of the transducer array (Carson and Zagzebski, 1981). It is produced by numerous sources, including poor inter-element isolation and undesirable modes of vibration of elements in transducer arrays. If the clutter level is significantly greater than -50 dB with respect to the maximum response at any depth, clinical results can be compromised due to artifactual "fill-in" of echo-free structures.

Measurements of axial resolution are done using the same approach as described for lateral resolution, again requiring the use of a calibrated sensitivity control on the instrument. Several workers recommend that axial resolution at the -20 dB level be assessed during routine testing (Carson and Zagzebski, 1981; Zagzebski, 1983). Possible phantoms for carrying out routine tests include the following:

(a) tissue-mimicking phantoms that have nylon reflectors with different spacings (*i.e.,* 3 mm, 2 mm, 1 mm and 0.5 mm).

(b) phantoms with a wedge, providing planar surfaces that are nearly perpendicular to the scanning window; a variable separation between planes exists. An example is the SUAR phantom described by Carson and Dubuque (1979).

To measure elevational resolution at the range of concern it is necessary to image a reflector whose dimension perpendicular to the scanning plane is negligible compared to the elevational resolution. With the instrument sensitivity adjusted at a specified level above threshold for display of this reflector, the reflector or the transducer assembly is translated in a direction perpendicular to the scanning plane; the translational distance required to make the reflector image disappear from the display is one-half the elevational resolution at the specified sensitivity level above threshold.

17.2.2 *Image Display Characteristics*

Significant differences in B-mode image quality are related to the gray-scale transfer curve, or the mapping of echo amplitude variations into gray level variations on the display and hard copy. Minimal characterization of the gray scale display characteristics of a scanner includes assessment of the displayed echo dynamic range. This is the ratio of the minimum reflection coefficient of a reflector causing the maximum display response to the reflection coefficient of a reflector at the same position which is just noticeable at the system display.

The displayed echo dynamic range may be measured using electronic burst generators coupled electrically (Carson, 1976) or electronically (Duggan and Sik, 1983) to the instrument. Alternatively it can be measured using specular reflectors having different reflection coefficients (Zagzebski, 1983). In state-of-the-art imaging systems the displayed dynamic range exceeds 40 dB; most systems have "preprocessing" and "postprocessing" functions, with operator controls that vary the dynamic range.

17.3 Basic Tests of M-Mode Systems

An M-mode record is an intensity modulated display, yielding the relative distance from the transducer to reflectors vs time. M-mode displays frequently are used to estimate structure dimensions, reflector movement patterns and reflector velocities. M-mode systems, either as stand alone units or units that are integrated into B-mode scanners, require separate tests to ensure consistent operation. Basic performance tests, that can be carried out by clinical operators, include assessment of the distance calibration accuracy; determination of the accuracy of time markers; checks of the sensitivity; and evaluation of hard copy recording of M-mode traces.

17.3.1 *Distance Calibration Accuracy and Time Markers*

Distance calibration accuracy may be carried out using any phantom or test object filled with a medium of known speed of sound and that has reflectors with known spacing. The measurement procedure is the same as that outlined in Section 17.2. Timing marker accuracy may be estimated using a stopwatch or by injecting 60 Hz electrical noise into the display (Carson and Dubuque, 1979; Banjavic, 1983). The latter can be done with systems that are equipped with electrocardiogram display and leads by simply grasping one of the leads

and adjusting the ECG display sensitivity for a convenient (noise) signal amplitude (Carson and Dubuque, 1979; Banjavic, 1983).

Distance measurements on M-mode records are expected to be within ± 1 percent of the actual distance between reflectors in the phantom. Time markers should be accurate to within ± 10 percent. For systems that are used regularly in M-mode (2 to 6 studies per day), these checks should be carried out at least quarterly.

17.3.2 *Sensitivity*

Just as with a manual or real-time B-mode scanner, it is important to verify that the maximum sensitivity of an M-mode system remains unchanged. This may be done by observing the maximum depth of visualization of echo signals from volumetric scatterers within a tissue-mimicking phantom. The procedure is similar to that discussed in Section 17.2 above. For 3.5 MHz transducers or higher, the penetration depth should not vary by more than ± 1 cm.

For M-mode systems that are integrated into B-mode scanners, the echo display properties in one mode should be close enough to those in other modes that it is not necessary to vary the sensitivity and power control settings when switching from one mode to another. A useful performance test is whether the signal amplitude for just displaying an echo (called "display threshold") is the same for each mode. M-mode and B-mode can be compared by measuring the maximum visualization depth for both display modes. The ratio of these two depths should not vary by more than that which would result from the ±1 cm tolerance on the maximum visualization for each component.

17.4 Ultrasonic Doppler Systems

17.4.1 *Ultrasound Doppler Instruments.* Ultrasound Doppler instruments, either stand alone devices or components of "duplex" ultrasound scanners, are used in many imaging departments. Their special circuitry requires different testing protocols and concepts from those described for pulse-echo scanners. In particular, attention must be given to the motion detection capabilities of these instruments and to the ability of the instrument to isolate Doppler signals from a region of interest and display characteristics of the velocity pattern from the selected region. Emerging tests for ultrasonic Doppler equipment are described in an IEC Draft Standard (IEC, 1985). Few additional references are available that describe system tests

of Doppler instruments. However, phantoms containing fluids flowing in simulated vessels embedded within tissue-mimicking material are available from several manufacturers of phantom equipment, and quality control tests can be carried out by use of these devices.

17.4.2 *Doppler Tests*

Tests of Doppler devices should address the Doppler signal sensitivity and noise level and the accuracy of flow readout.

17.4.2.1 *Doppler signal sensitivity and noise level.* This can be measured using a phantom that has moving scatterers with a backscatter coefficient in the range of interest (Boote and Zagzebski, 1985). Alternatively, the IEC Draft Standard (IEC, 1985) proposes the use of strings or pulleys in a water medium. For both tests the moving target/fluid may be placed under a block of tissue-equivalent material. This assembly should allow testing through different path lengths of the attenuating material.

If an adequate tissue-equivalent phantom is available, *i.e.*, one in which the fluid scatter level mimics that of blood and the attenuation coefficient in the medium is in the range of 0.5 to 0.7 dB cm^{-1} MHz^{-1}, then close correlations can be drawn between the Doppler signal-to-noise ratio at some depth in the phantom and in the patient. One way to test the sensitivity is to determine the maximum range in the phantom from which Doppler signals (that are well within the frequency band pass of the output filter circuitry of the instrument) can be detected (Boote and Zagzebski, 1985). Alternatively and perhaps less subjectively, the range at which the signal-to-noise ratio is less than or equal to, for example, 6 dB can be determined.

17.4.2.2 *Accuracy of flow readout.* Most Doppler systems are linked to microprocessors that provide a display of the reflector velocity or the Doppler signal frequency spectrum vs time. The accuracy of this flow readout system should be checked periodically, since the velocity waveform and its maximum value are relevant in many diagnostic procedures. The waveform calculation generally involves a fast Fourier transform (FFT) processor and a user-controlled cursor line to indicate the flow direction with respect to the sound beam orientation.

Flow readout accuracy may be tested with a Doppler flow phantom with an output reproducible to within $\pm$ 5 percent.

17.4.2.3 *Range gate accuracy.*

On "duplex" instruments a Doppler sample volume cursor is presented on the B-mode image. The cursor identifies the location from which range-gated Doppler signals are recorded. The accuracy with which the cursor position on the image indicates the actual Doppler sample volume location should be inspected, either using flow phantoms (Boote and Zagzebski, 1985) or other test devices (IEC, 1985).

17.5 Other Considerations

17.5.1 *Care and Maintenance*

A quality control program should include routine maintenance procedures to assure safe, effective operation of imaging instruments. For diagnostic ultrasound scanners this includes inspection for frayed cables, including those that connect to the transducer assembly, to the hard copy recording device and to foot switches and other external devices. Maintenance also should include inspection and cleaning of any air filters which the user is directed to maintain. These must be kept clean to insure adequate air circulation around electrical components. The operator's manual of the instrument should be consulted for instructions regarding which filters may be removed and cleaned by clinical personnel.

17.5.2 *Operator Training*

It is recommended that operators of clinical imaging equipment be trained in the physical principles as well as the clinical aspects pertinent to each imaging modality. For ultrasound instruments, operators should be instructed in proper selection and setting of imaging parameters for a given study, including choice of transducer assemblies. In addition they should be capable of carrying out basic quality control tests of scanners. Finally, all operators should be aware of steps that can be taken to minimize potential risk associated with exposure of patients to ultrasound energy (NCRP, 1983).

17.5.3 *Acoustical Exposure Measurements*

There is a growing awareness among ultrasound imaging users of the relevance of acoustic exposure levels from diagnostic ultrasound

instruments. The use of minimum practical exposure levels and exposure times is prudent (AIUM/NEMA, 1981; NCRP, 1983). Ultrasound equipment manufacturers now provide data on the acoustic power levels and intensities produced by instruments they market. These data provide the user with information which can be used when comparing different systems prior to purchase. Perhaps more importantly, the data can identify potentially high-intensity operating modes and control settings for a given instrument. Equipment users are encouraged to consult the exposure data, both when selecting diagnostic ultrasound equipment and when questions arise regarding minimizing the intensity levels during routine clinical use.

Those laboratories and facilities equipped with the specialized instruments required to make acoustical exposure measurements are encouraged to carry out such measurements on clinical scanners. This procedure would begin providing acoustical exposure data for many instruments for which the power levels and intensities have not been measured. Secondly, it would be useful both to the manufacturer and the users to have independent measurements of the acoustic output levels performed. Finally, field tests are the only means of detecting whether the acoustical output varies from the time an instrument was manufactured.

Instruments required for measuring acoustical output include a calibrated, miniature hydrophone, a water tank with a three-dimensional scanning apparatus, an oscilloscope, and a radiation force balance. A description of this equipment, as well as its calibration and usage for measuring the acoustical intensity from ultrasound scanners, is available in AIUM/NEMA, 1981.

18. Quality Control in Magnetic Resonance Imaging

18.1 Introduction

There are no generally agreed upon quality control procedures for magnetic resonance imaging (MRI). It is not clear which of a large number of measurements that can be made actually correlate with diagnostic image quality. Additionally, the technology is diverse for machines operating at different magnetic field strengths and with different hardware and software configurations. This makes it difficult to prescribe simple, universally applicable methods for controlling the quality of the images. Until standards for image quality are developed, procedures will have to be tailored to each installation. Most equipment manufacturers provide a quality control phantom and semi-automatic routines for daily tests.

The following recommendations are, therefore, general. They include a basic set of measurements that should be made daily to make sure that the machine is stable. These are measurements of spatial uniformity of the signal, stability of the signal-to-noise ratio, geometric distortion, slice thickness, slice spacing, slice profile and the relation of slice position to patient position. They do not require hardware or software modifications but use the machine in its normal imaging configuration.

When relaxation times are being measured from images, a relaxation time measurement should be performed daily until its stability is established. Thereafter, it need only be performed weekly or even monthly if the measurements are very stable.

If imaging is done in more than one orientation (sagittal, coronal, transverse) the measurements should be made in each of the relevant planes.

If imaging is done with more than one set of coils, measurements should be made for each major coil configuration.

All newly installed pulse sequences should be tested at least once, including once for each slice thickness and imaging plane that will be used.

18.2 Quality Control Procedures

18.2.1 *Signal-to-Noise Ratio*

The ratio of the signal intensity over a uniform part of the phantom to the standard deviation of the intensity of the background noise may be the best single figure of merit for monitoring day by day system performance. A phantom is required that adequately loads the coils and that has relaxation times in the biological range. Great care must be taken to use a phantom geometry that does not produce artifacts peculiar to the phantom and not found in biological material. For example, it may be preferable to put the filler in multiple small chambers rather than in a single large one to avoid inhomogeniety due to rf surface effects and inhomogeneity due to motion of the filler. The daily measurements must also be made at the same temperature. The same pulse sequence must be used for each measurement.

Once a suitable configuration of the phantom has been devised, it should be imaged daily and the signal-to-noise ratio at specific locations compared.

18.2.2 *Spatial Uniformity of the Signal*

The same phantom that is used for signal-to-noise ratio measurements can be used to measure spatial uniformity by obtaining measurements from multiple positions in the image and comparing the variation in the intensity of the signal.

18.2.3 *Geometric Distortion*

A phantom with distinctly identifiable targets in some grid pattern such as an array of squares or circles can be used to test for gross geometrical distortion.

18.2.4 *Slice Geometry*

A slice profile phantom consisting of a helix or a ramp can be scanned to determine slice position with reference to the patient position, slice thickness, slice spacing, and slice profile. The relation between slice thickness and slice spacing is important in multislice data collection techniques. Slice profile will vary with technique and

may be more useful to know than slice thickness. Thickness is usually expressed as the width of the slice profile at half maximum intensity, but the portion of the anatomy mapped into the image using equally thick square and gaussian profiles will be different. Slice profile will also effect relaxation time measurements.

18.2.5 *High Contrast*

High contrast spatial resolution is commonly considered to be correlated with the ability to see small high contrast objects in the image. Phantoms consisting of aqueous solutions of paramagnetic ions containing solid pins of various sizes have been used to estimate spatial resolution at high contrast. An alternative method uses solid phantoms with the holes drilled into them that are filled with signal-producing filler solutions. If such measurements are made, it is important to recognize that they are not absolute measurements of spatial resolution but are highly dependent upon the geometry of the phantom, the spin density and relaxation times of the material used to produce the signal, and the pulsing sequence used to produce the image.

18.2.6 *Relaxation Times*

When T1 and T2 measurements are made from images, the precision and accuracy of the measurements should be determined by making measurements on standard materials that have been measured independently of the machine that is being calibrated. A phantom containing materials with at least three different known T1 and T2 pairs that span the biological range should be imaged using the same pulsing sequences that will be used in clinical cases and the computed values compared to the known values.

18.3 Quality Assurance Phantoms for Magnetic Resonance Imaging

The procedures just described refer to phantoms and phantom materials. Ideally, tissue equivalent materials should be used to calibrate imaging machines. This means that the materials should have spin density, relaxation times, conductivity and dielectric constant at the imaging frequency that are comparable to tissue. Most simple materials such as solutions of paramagnetic ions do not have

all of these characteristics and until such materials are developed some compromise must be made. Aqueous solutions of paramagnetic ions such as copper, nickel, manganese or gadolinium can be used. Solutions of copper sulfate ranging from 0.1 to 10 millimolar are commonly used, but although they are stable and easy to prepare, when the T1 matches tissue, the T2 will be considerably longer than that of the tissue. Sodium chloride (about 50 mM) can be added to the solution to match the conductivity of the body or can be included in a separate insert. Mixtures of the polysaccharide agarose and paramagnetic ions have been suggested for use as tissue equivalent fillers for phantoms (Mitchell *et al.,* 1986).

A useful general quality assurance phantom is one that consists of a square 5 × 5 array of removable cylinders containing either an aqueous solution of a paramagnetic ion or a material with tissue equivalent relaxation times. When each of the cylinders contains the same material, the phantom can be used to test spatial uniformity of the signal, and signal-to-noise ratio. The appearance of the array in the image will also show whether there is any gross geometric distortion. The phantom must be flexible enough to be scanned in three orthogonal positions so that parameters can be tested in any direction. The cylinders can also be filled with material of different relaxation times to calibrate T1 and T2 measurements.

A useful slice profile phantom consists of a diagonal ramp of known thickness. A layer of oil or an aqueous solution of paramagnetic ions between two sheets of plastic can be used. This phantom must also be flexible enough to be rotated into position to measure the slice profile in three orthogonal positions.

19. Video Systems

Video systems are used to display and record the diagnostic image for all of the newer modalities, *e.g.,* computerized tomography, ultrasound, digital radiography, magnetic resonance imaging. In addition, video systems are also being used to record images for diagnostic purposes in conventional fluoroscopy and cardiac radiology. These systems tend to be overlooked during specification, acceptance testing, and quality control since their total cost is a small fraction of the cost of, for example, a computerized tomographic system. In the past much attention was paid to the quality of the image as it resided in the computer memory, *i.e.,* the front end of the system, with few or no tests being carried out to determine whether the system between the computer and the eye of the imaging physician was functioning properly. However, it is very important to provide the proper level of quality control for video components throughout the diagnostic imaging department.

19.1 Video Signal Levels and Line Termination

Monitoring the characteristics of the video signal and ensuring proper line termination are as important as monitoring any other quantity of a fluoroscopic or video imaging system. If the video system produces a signal which complies with the RS-170 broadcast standard (EIA, 1957), then the signal characteristics are well defined. All composite video signals should be 1.0 volt peak to peak including synch. If the video signal does not meet the RS-170 standard, then it may be impossible to record the signal on conventional video tape recorders.

The following indented material is tutorial in nature. The reader is referred to the literature for more detailed discussions of video systems (Hansen, 1969; Biberman and Nudelman, 1971; Biberman, 1973; Grob, 1975; Buchsbaum, 1975; 1978; Curry *et al.,* 1984; Sandrik, 1984).

> If the signal is less than 1.0 volt the signal-to-noise ratio will be less than optimum. In this case the video monitor may be able to amplify the signal and display the result on the monitor,

but with more noise than is necessary. If the signal is to be recorded using a video tape or disc recorder additional noise will be added to the low level signal further reducing the signal-to-noise ratio. If the composite signal is greater than 1.0 volt the video chain may "clip" the signal, eliminating video information above the 1.0 volt level. This is especially true if the video signal is to be recorded on an analog recorder or if the signal is to be digitized.

Incorrect video signal levels may be due to several factors including incorrect video amplifier adjustments, insufficient light reaching the video camera tube, or improper termination of the video signal cable. Although all possibilities should be investigated, first determine if the video termination is correct. Video systems are designed to operate with a 75-ohm termination on the *end* of the video cable. If this termination is not present, the video signal will be greater than 1.0 volt and reflections may occur along the cable resulting in "ghosts" in the video image. If more than one 75-ohm termination is present then the signal will be reduced. If only one 75-ohm termination is present, but it is not located at the end of the cable, the signal level may be correct but signal reflections and "ghosts" may still occur.

For signals meeting the RS-170 standard the video signal can be observed using a video waveform monitor, a commercially available piece of broadcast television equipment. For non-standard video signals an oscilloscope and a video line finder may be used to allow easy examination of specific video lines. In addition to observing the video signal levels, video waveform monitoring allows for a complete, quantitative analysis of fluoroscopic and video signals and image quality (Gray *et al.*, 1983; 1984b).

The video signal levels should be within ± 5 percent of those specified in the RS-170 standard for conventional systems and within the same limits for the specified signal level for nonstandard systems.

The video signal levels should be checked every six months or when service is performed on the video system. In addition, the terminations should be checked every six months, whenever video signal levels appear to have changed, or whenever video image quality is degraded.

19.2 Television Monitors

Television monitors are the final link in the video chain, presenting the visual image to the imaging physician for diagnostic pur-

poses. Included here are not just TV monitors used for fluoroscopy but monitors for viewing any video image, *e.g.*, CT, MR, DSA, ultrasound. A large proportion of the problems involving poor image quality or requiring x-ray service is related to misadjustment of the TV monitor.

The TV monitor should be set up using a commercially available video signal generator. The TV monitor can then be adjusted to provide the maximum resolution, minimum distortion, and appropriate brightness and contrast levels to ensure that all of the information in the video signal is available to the imaging physician for diagnosis. The brightness and contrast for well designed monitors are adjusted by turning both the brightness and contrast controls completely counter-clockwise (so no image is visible). Adjust the brightness control so that the video scan lines, or raster, are just perceptible. The contrast control is then adjusted to obtain an image containing all of the shades of gray in the signal generator gray-scale with a complete range of brightnesses (from black to white). The contrast should not be increased beyond the minimum needed to obtain a pleasing image or the scanning spot will bloom, or increase in size, resulting in a defocused, or "fuzzy" image. Note that brightness should not be changed while adjusting contrast if the darkest step of the gray scale does not change brightness level.

It is essential that the TV monitor be adjusted, using the video signal generator, with lighting conditions identical to those under which the imaging physician will view the images since lighting conditions will alter the appearance of the monitor image. In order to make use of the entire video signal and ensure that all information is displayed with optimal contrast the TV monitor should be viewed in a dimly lit room with no reflections on the monitor viewing screen. If the viewing room is brightly lighted then the contrast in the image may be reduced by a factor of two or more (Gray *et al.*, 1985). Once the TV monitor is properly adjusted, the displayed image may still not be optimum. To correct this, changes should be made in the *source* of the video signal to ensure that the correct information is available in the video signal. For example, if a fluoroscopic image appears distorted then the intensifier-optics-video camera system should be checked to determine the cause of the distortion; if contrast is not optimized then the kVp should be adjusted for fluoroscopic systems or the window width changed for CT or MR systems.

In addition to the traditional broadcast video signal genera-

tors the Society of Motion Picture and Television Engineers has developed a test pattern for the evaluation of medical video display devices (Gray *et al.*, 1985).

For the displayed images from the commercially available signal generators, all 10 percent steps of the video gray scale should be visible; distortion should be minimal; and the resolution should be that specified by the manufacturer for the particular TV monitor.

Television monitors should be evaluated at least every six months or whenever image degradation is suspected. If brightness and contrast controls are readily available to the operator, it may be worthwhile to evaluate the TV monitors more frequently, using a video signal generator. TV monitors should also be evaluated any time service is performed on the video imaging system.

19.3 Hard Copy Cameras and Visual Displays

Many imaging systems use a hard copy (HC) camera[6], also called a multiformat camera, and visual displays, *e.g.*, television monitor. As in any imaging system, the image quality is limited, or degraded, by every link in the chain, and the HC camera and visual display can be the limiting link if proper quality control measures are not taken.

Usually the image is viewed on the visual display, and the window widths and levels are adjusted to obtain an image with the appropriate appearance. If the visual display and HC camera are properly calibrated and maintained, the HC camera should produce a film that appears similar, though perhaps not identical, to the visual display. (This should be true for all image sizes produced by the camera.) To accomplish this, the video signal to the camera and visual display must be optimum, the two monitors (the one in the HC camera and the one used for visual display) must be properly adjusted, and the photographic processor must be operating at the appropriate level. The video signal must also be optimum for laser cameras. For laser cameras utilizing a video signal as input or digital information transferred from the imaging system, it will be necessary to assure that the camera is appropriately calibrated.

In order to produce a hard-copy image which has an appearance similar to the visual display the camera and display must be properly adjusted, the processor must be operating at an

[6]Laser cameras and video-type cameras are included in hard copy cameras.

optimal and controlled level, and the photographic material must be appropriate for the imaging task. Standard dual-emulsion radiographic films should *not* be used since the scatter and spread of light in a dual-emulsion film will severely degrade the quality of the image. Instant print materials (*e.g.*, Polaroid) offer the advantage of rapid processing and do not require a photographic processor. However, the dynamic range of such papers is limited so that if all available shades of white to black in the video signal are to be reproduced in one image, the contrast must be reduced to a relatively low level. Dry silver papers offer advantages similar to instant print materials. However, in terms of the ability to reproduce the information in the video signal the dry silver papers are even more limited than the instant print materials. Both the instant print and dry silver materials may be suitable for limited uses such as in obstetrical ultrasound applications. Direct imaging on photographic paper is also a possibility. Special photographic papers can be exposed in a standard hard-copy camera and processed in a conventional radiographic film processor. These materials are capable of reproducing the same density range as the single emulsion films usually used for this purpose. However, as with instant print materials, the range of densities that can be visualized under normal room-light conditions is limited unless the prints are transilluminated, which superimposes the texture of the photographic paper on the image.

Video signals, adjustment of the visual display (this requires the same technique as described in Section 19.2, Television Monitors), and photographic processing quality control have been discussed previously. However, obtaining optimal image quality from a HC camera has a few special problems and pitfalls. First of all, it is essential that the film selected for use be of the appropriate spectral sensitivity, speed, and type, *i.e.*, single emulsion only (Schwenker, 1979). The photographic processor must be controlled with this same emulsion. The control limits described for standard radiographic materials are applicable.

The image appearing on the HC camera cathode ray tube (CRT) should be a dim, low contrast image. This ensures that maximum sharpness is obtained by avoiding flaring of the electron beam that writes the image on the CRT. The exposure time should be set to approximately 1 second to allow sufficient time for the raster erase or blending circuit to smooth the raster lines in the image. Detailed set-up and quality control procedures are provided in the literature (Gray *et al.*, 1983; 1985).

A standard test pattern has been developed for set-up and quality control of HC cameras and visual displays as well as for specification and acceptance testing (Gray *et al.*, 1985) and has been adopted as a "Recommended Practice" by the Society of Motion Picture and Television Engineers (SMPTE, 1986). This pattern contains low and high contrast resolution targets, a grid for distortion measurement, and a gray scale. The pattern also includes low contrast areas inset in the dark and light areas of the gray scale to allow a quick visual check to determine if all of the video signal is being properly recorded on film or is visible on the visual video display. This pattern is available on digital magnetic tape from several medical imaging equipment vendors and also from an analog signal generator.

All quality control films should be evaluated using a densitometer, with the data plotted on control charts. Control charts similar to those for the photographic processor quality control program can be used.

The quality control program should monitor a mid-density level produced by the 40 percent patch of the SMPTE test pattern (density of approximately 1.15), the density difference between the 10 and 70 percent patch (a density difference of approximately 1.20), and a low density area produced by the 90 percent patch, which is just above the base-plus-fog level of the film (at a density of approximately 0.25). If the photographic processor is being maintained with control limits of ± 0.10 for the mid-density, then the HC camera films should be maintained to ± 0.15. If the majority of the data points on the photographic processor control chart fall well within the ± 0.10 control limits, the HC camera films can be maintained to ± 0.10.

The operating levels and control limits should be the same for all HC cameras. This ensures that all information in the video signal is recorded on the film. Changes in the window widths and levels, from those used prior to camera optimization, may be necessary to produce satisfactory images once the HC cameras have been optimized. The only time the brightness and contrast settings of the cameras should be changed is when this change is indicated by the SMPTE test pattern.

The visual displays should be checked daily, with the SMPTE test pattern, using the same room lighting conditions normally used for viewing clinical images. The densities and contrast for HC cameras should be checked daily, after the photographic processor has been checked and is in control. In addition to the densities of the films and appearance of the gray scale, the high and low contrast resolution patches in the pattern and the overall appearance of the images

should be checked weekly for both the HC camera films and the visual video display.

19.4 Video Tape, Disc, and Digital Recorders

Analog video disc and tape recorders share similar problems and must be evaluated regularly. Digital recorders are becoming more widely available for video systems and are used for "last image-hold," for image storage and for integrating video frames to reduce the appearance of quantum mottle. These recorders should be checked using a signal generator to ensure that the manufacturers' specifications are met. However, because these devices are solid state rather than mechanical systems, there are fewer inherent problems and drift is not common—the system either functions properly or not at all.

Video tape and disc recorders are becoming more popular in diagnostic imaging. Though the smallest video tape formats (8 mm, VHS, and Beta) do not have sufficient bandwidth capabilities and exhibit excessive noise for many diagnostic studies they may be satisfactory for some diagnostic imaging applications. The smallest format tapes may be adequate for recording real-time ultrasound studies. The ¾-inch format tapes may prove adequate for high contrast examinations, *e.g.*, GI examinations. However, where high quality is required, such as for cardiac catheterization studies, 1-inch tape systems with 5 MHz bandwidths will be necessary. One-inch tape recording from an optimized 525-line, 5 MHz bandwidth video system has been shown to be superior to higher bandwidth, higher line-rate systems for cardiac studies (Gray *et al.*, 1984c; Holmes *et al.*, 1984).

Analog video disc recorders have become a popular recording medium especially for mobile C-arms where the "last-image-hold" feature is an advantage to the surgeon in the operating room. In addition, they are used in some digital subtraction angiography systems as the primary rapid image storage device.

Since the bandwidth of most analog recording devices is less than that of the image forming chain, degradation in resolution or sharpness of the images can be expected. Noise may also be introduced due to the additional electronics required for the video recorders and, more importantly, due to the inherent noise from the recording media. Drop-outs (dynamic black or white spots in the image) are introduced by most analog record-

ing media. Distortion and noise will be increased due to the buildup of dirt on the recording heads. Finally, due to the inherent stretch in the recording media, imprecise timing of tape transport, and variations in recording head and disc rotation speeds, jitter, a random horizontal shift of individual video scan lines, will degrade the image. (Jitter from the recording system can be reduced significantly by the use of a time base corrector, or TBC, as an integral part of the recorder playback system.)

Analog video recorders should be evaluated using a video signal generator. Two minute segments of each of the test patterns (resolution, gray scale, distortion, etc.) should be recorded on tape and then viewed on the monitor to be used in the clinical setting. (Note that the TV monitor should have been evaluated as discussed in Section 19.2.) Since most generators specify the resolution patterns in megaHertz, it is easy to determine if the recorder conforms to the manufacturer's specifications.

Only a black and white TV monitor should be used to view black and white diagnostic images. Color TV monitors further limit the resolution and image quality because of an inherently low bandwidth and the color matrix pattern of the cathode ray tube (CRT).

In evaluating a video tape recorder using a signal generator it is difficult to determine whether any problems noted are due to the recording or playback function of the recorder. In addition, if video tape players, *i.e.*, without recording capability, are to be evaluated, a pre-recorded test tape is needed. The Society of Motion Picture and Television Engineers (SMPTE, 1983) provides video tapes in several different tape formats to evaluate the quality of the video tape player and recorder playback functions. These tapes are useful for both monochrome and color video systems but are especially helpful in setting hue and chroma levels for color video systems.

Image quality is difficult to specify for video recording systems. However, for images recorded from the signal generator and displayed on the monitor all 10 percent steps of the video gray scale should be visible; resolution should be that specified by the recorder manufacturer; distortion should be minimal; and dropouts and jitter should be minimal. The gray scale should be recorded and replayed with the same fidelity available when the signal is displayed directly (without recording). However, an increase in noise will probably be apparent and can be quantitated by measurement of the video signal from the analog recorder using a video waveform monitor or line selector and oscilloscope. Distortion should be minimal.

After evaluating an analog recording device with the video signal generator, a series of test images from the imaging chain should be

recorded and evaluated. For example, a high and low contrast lead test pattern imaged fluoroscopically and recorded with the analog video recorder will provide an indication of how the whole imaging chain will function.

Analog video tape and disc recorders should be evaluated at least every six months. If they are used daily, a frequent schedule of manufacturer recommended preventive maintenance procedures, such as cleaning the recording heads, should be established along with more frequent checks of the quality of the recorded images. Digital recording systems should be evaluated at least every six months and all system functions should be checked.

20. Computers

Provided here are items which are not really "quality control" procedures for computers since most checks are preventive maintenance. The following material is provided for information and guidance.

Computers, for the most part, either work properly or they do not function at all. Since diagnostic imaging is becoming more and more dependent on computers for everything from imaging to record keeping to billing it is essential that the computer systems be reliable. A major key to reliability of the computer is preventive maintenance and service. Though this is, technically, not quality control it is good practice and one individual should be responsible to ensure that these functions are carried out on a regular basis.

Time must be allowed to all computer systems and computer based imaging systems for preventive maintenance. It is preferable that this time be scheduled and be during the working hours so that service personnel have the ability to order parts and obtain advice via telephone for difficult engineering problems.

Service personnel must be familiar with and follow the manufacturers' instructions concerning preventive maintenance. They should be aware of the manufacturers' recommendations concerning the frequency of preventive maintenance and follow the manufacturers' preventive maintenance manuals for each procedure.

To help ensure computer reliability it is essential that the computer room environment be dust free and maintained at about 68 °F (20 °C) with the relative humidity between 40 and 60 percent. The computer room should include an alarm system to alert the technologists if the temperature or humidity approaches the preset limits. This alarm system is essential since some computers are designed to automatically shut down if temperature or humidity limits are exceeded, interrupting operations and introducing the risk of losing important data.

Cleanliness is the major goal of the computer quality control program. The recording heads of digital tape drives should be

cleaned every month by service personnel. Floppy disc and analog disc recorders, used in some digital subtraction angiographic systems, must be serviced monthly by qualified service personnel. This service should include the cleaning of the recording heads. (Recording heads on hard disc systems do not require frequent cleaning since there is no contact between the heads and recording media.)

It may not be necessary to clean disc packs if these are stored and used in a clean environment. During use most disc drive units are virtually dirt free as a result of the high quality filter systems utilized.

Cleaning or changing of all computer equipment filters is essential and should be done at the frequency recommended by the equipment manufacturers. With most filters it is difficult to visually determine if they should be cleaned or changed since the filters are removing minute particles of dust. If the facility conditions are other than "clean," the frequency of cleaning or changing filters will have to be increased. Some filters cannot be cleaned and must be replaced, *e.g.*, filters on most disc drive units.

Many computer systems have diagnostic software tests designed to determine if problems exist in the computer components such as the memory, central processing unit, and tape and disc drives. These tests should be performed during every biweekly preventive maintenance check. The test of the memory and central processing unit should be continuous for approximately one hour in order to detect potential, intermittent problems. (Some imaging system computers run such tests continuously when the computer is not being used for data acquisition or display.)

Specific checks of recording head alignment are usually not required. The head alignment is mechanically stable and if the heads do become misaligned tape read errors will result, indicating a need for re-alignment.

Magnetic tape storage, analog or digital, requires the appropriate temperature and humidity conditions [68 °F (20 °C), 35 to 45 percent relative humidity], but the proper condition of the tape prior to storage is just as important (Wheeler, 1983). Before tapes are placed in long term storage they should be rewound under constant tension to ensure that tension is uniform throughout the roll. If the tension is not constant, the tape becomes distorted and warped resulting in reading errors upon retrieval. Magnetic tapes should be rewound periodically to avoid mechanical problems. For tapes which are prop-

erly wound on the reels and are stored under the proper conditions (temperature, humidity, and cleanliness) the rewind interval may be as long as three to five years, during which time the tapes should remain relatively error free.

21. Miscellaneous

21.1 Artifacts

When recording is by light-and x-ray-sensitive emulsions, part of the image obtained during the course of making, processing, and storage of the image may not be indicative of the actual structural relationships being imaged. These artifacts can be classified according to their causation as indicated below.

21.1.1 *Artifacts from Overlying Objects*

Those artifacts from radiopaque or radiolucent objects unintentionally allowed to remain between the device producing the energy to make the image (*e.g.*, the x-ray tube) and the device recording the image (*e.g.*, the film) are: mattresses, pads, pillows, items of clothing and items contained in the clothing; jewelry worn on the person; materials on the skin, hair, and in the soft tissue such as bandages, dirt, debris, salves and other medications; hair when fashioned into braids or coils; objects left or liquid (mainly contrast media) spilled on the patient or the receptor. Also included in this category are objects within the collimator which cause obstruction to the beam such as bolts, nuts, washers and other pieces of free metal particularly from the collimator, and incomplete insertion of a filter. To avoid these artifacts, the part of the patient to be imaged should be completely bare of clothing and jewelry or the patient, for privacy, should be covered only by light clothing or a sheet of uniform attenuation and there should be no objects remaining in any pocket or part of the clothing or sheet. The smaller the body part being imaged, the more appropriate is this caution. If medication, dirt, and debris cannot be removed from the skin and bandage or dressings removed, the imaging physician should be made aware of this before interpretation of the image. Similarly, the imaging physician is to be informed of any hair braid or coil and any tattoos which cannot be excluded from the image zone. Receptor surfaces and x-ray tables should be kept clean of solid materials and liquids, either wet or dried, partic-

ularly contrast media. Objects in any body cavity should be removed or their presence made known to the imaging physician.

21.1.2 *Artifacts Caused by Improper Use of Imaging Equipment*

21.1.2.1 *Multiple Exposure of the Receptor.* Artifacts caused by *multiple exposure of the receptor* can be prevented by ensuring that a film is not used for more than one exposure and by ensuring that all devices used in initiating the image make only the single intended exposure. This can be achieved by keeping exposed and unexposed film separate and always removing unused cassettes from the fluorospot unit or radiographic table after completion of examinations. The exposure switch and the timer of the equipment should be checked to assure precise functioning. When positioning a cassette with overlying lead rubber or lead plate to divide it for multiple exposures, care is needed to avoid re-exposure of the already exposed areas and to avoid initial unintentional exposure of the area to be exposed later.

21.1.2.2 *Grid Malfunctioning or Grid Misuse.* Artifacts caused by *grid malfunctioning or grid misuse* are avoided by keeping all grids in good repair, and by ensuring that the technologist always activates the movable grid mechanism, if this is not automated.

Damaged grids and grid cassettes should be replaced.

Grid misuse is to be avoided. Focused grids shall not be used upside-down, and, if two grids are to be used superimposed, they shall be positioned at right angles to each other. The technologists should ensure that the beam of radiation is perpendicular to the short axis of the grid and should ensure that the x-ray tube is at a proper distance from a focused grid.

21.1.2.3 *Improper Film and Screen Care, Handling, Processing, and Storage.* Artifacts caused by unwanted light striking the film can be avoided by checking cassettes for light leaks and ensuring that the darkroom has no constant or momentary light leaks. Constant light leaks are defined as those resulting from defects in the walls, floor, ceiling or entrance of the darkroom, and excess light from a defective safelight casing, an improper bulb or filter, a faded filter, or operation of the safelight at too short a distance from the film or at excess wattage. The film manufacturer's recommendation should be followed for type of film in use. Momentary light leaks are defined as those occurring when a door to a darkroom is left open, when a film bin is left open, or when other than a safelight illuminates the darkroom. All of these are inadvertent and caused by human error.

Static artifacts are to be avoided by maintaining the darkroom at

a relative humidity of 40 to 60 percent at 65 to 75 °C, and by treating cassette intensifying screens with antistatic compounds specifically recommended by the manufacturer of the screens. Care by personnel in loading and unloading cassettes and magazines is also essential in avoiding static artifacts. This is also true in the avoidance of crinkle marks and other physical damage to the emulsions (see Section 6). Boxes of film should be stored on edge and at proper humidity and temperature.

Obstruction to the desired radiation reaching the film within the cassette or magazine is avoided by not allowing paper, film fragments or other solids to enter the cassette and by not allowing fluids to soil film, screen, or cassette surface. Screen cleaner should be used with care so that streaks are avoided. Screen cleaner should be allowed to dry before cassettes are closed. Poor film screen contact should be examined for and corrected regularly. Film in its original box, and in its cassette or magazine, whether in the x-ray room or in storage, should be protected from the artifacts caused by stray x-ray radiation. Lead protected containers or passboxes should be used, or the film should be placed at a distance from radiation sources.

In processing by manual methods, artifacts from faulty placement of a film in the fixer before placement in the developer are due to human error. Artifacts from weak or oxidized developer can be avoided by adherence to strict rules for use and replenishment of solutions. Likewise, certain artifacts can be avoided by maintaining clean film hangers and ensuring that films are hung sufficiently far apart to avoid their adherence to each other during processing and drying.

In automated film transport systems, artifacts can be avoided by ensuring that lubricants for mechanical parts do not come in contact with the films and by ensuring that films are fed into the processor so that they do not fold on themselves or overlap each other. Linear artifacts, usually caused by the rollers of the processor, can be avoided by proper preventive maintenance.

21.2 Mechanical Safety

Instructions in the use of the mechanical parts of radiologic equipment should be as much a part of the orientation of new employees as the other aspects. Instructions should include how the employees are to recognize hazards to patients and to equipment and how to respond to damage situations.

All patient support devices such as foot boards, shoulder braces or harnesses, and head holders are to be checked for security in locking.

Such devices must be able to support up to 300 lbs. Brakes and locking devices on carts and beds must be checked for engagement when patients are moved on or off a radiographic table. For any movable part of the radiologic apparatus such as table top, moving grid, tube hanger or stand, spot film device, tilting table or tomographic arm, it must be ascertained that the moving part cannot come into contact with any part of the patient in a way that can cause injury to the patient. Systems with a counter-balance shall incorporate a safety mechanism, backup cable or spring to prevent free fall in the event of failure of the primary mechanism. Mobile equipment is to be provided with brakes to prevent uncontrolled movement. Mobile equipment should be inspected at frequent intervals since it is more susceptible to mechanical damage.

An inflammable or explosive anesthetic gas should not be used in the radiology department. Mobile radiologic apparatus which may be used in areas where there are flammable or explosive anesthetic gas mixtures shall be spark and explosion proof.

21.3 Quality Control of the Imaging Physician's Reading Room

Quality control of the imaging physician's reading room is to be directed toward providing optimal conditions for the interpretation of the images recorded on film or displayed on a TV monitor.

For optimal viewing, the illumination intensity for the individual viewboxes installed in groups should differ from each other as little as possible. The luminance of the viewboxes located where films are checked for quality should be similar to that of those located where radiographs are to be read. Nonuniformity of bulb manufacture and discoloration of the viewbox viewing surfaces with age are causes of improper and inconsistent illumination. Only one type of bulb supplied by a single manufacturer should be used for all viewboxes of an entire department. Bulbs should be replaced at least once a year. Defective switches and fluoroscent bulb starters should be immediately replaced.

Motorized film viewers should have periodic maintenance checks of their mechanical components and activation devices. When viewboxes are mounted together, individual on-off switches are necessary to avoid flooding the eye with light from surfaces where radiographs are not mounted. Viewboxes should be placed in a room so as to minimize illumination from one box striking the front surface of films mounted on another and producing glare. Other illumination

in the room should be subdued, as visual performance decreases when illumination of the room is increased. The limitation of general room brightness is particularly crucial for viewing images on TV monitors.

It is recommended that viewboxes be thoroughly cleaned inside and out at least twice a year. The outer viewing surface will need to be cleaned more often if it is soiled.

An effort should be made to suppress the noise level in the reading room. The use of carpeting and acoustical ceiling and wall surfaces is recommended. The room should not be used for other than its primary purpose, nor should it be part of a hospital or department traffic way. Consultation rounds and teaching-patient care conferences should be held elsewhere to minimize distractions.

Appendix A

Summary of Quality Control Tests

This section contains summary tables of much of the information discussed in the previous sections. These tables indicate whether a test is "essential" or "desirable." An essential test is one which must be included in a quality control program regardless of the size of the department. A desirable test is one which provides valuable information about the image quality and functioning of the equipment but may require special equipment or advanced training of personnel beyond the means of many imaging departments.

For each test listed in a table, the appropriate section number is provided. In addition, a typical test device and suggested performance criteria are indicated. The performance criteria may be based on regulations (FDA, 1986) or may result from the experience of users. It may be necessary to adjust the performance criteria under special circumstances. For example, most manufacturers specify rather broad performance criteria for kVp since the single specification must apply over the entire working range of the generator, *e.g.*, from 30 to 150 kVp and from 50 to 1,000 mA. If the use of the generator is limited to a few mid-range mA stations and from 50 to 100 kVp, a practice which is not uncommon in many radiology departments, then much tighter performance criteria (control limits) can be used, *e.g.*, ± 2 to 3 kVp. Likewise, wider control limits than the suggested performance criteria may be imposed. However, this should only be done under limited circumstances, on a temporary basis, and with the knowledge of the physician responsible for the equipment who understands the effect on the quality of the images and diagnosis.

All quality control tests should be carried out on a regular schedule. The tables in this section indicate the *minimum* frequency for the tests. However, there are other points which must be considered when determining the frequency of tests.

The frequency should be increased if the equipment falls into any of the following categories:

1. If the equipment exhibits significant changes between scheduled quality control tests;
2. If the equipment is used for an exceptionally high volume of procedures, *e.g.,* mobile radiographic equipment used for more than 10 to 15 procedures per day; and
3. If the equipment is used for invasive or critical procedures, *e.g.,* cardiac catheterization or vascular procedure laboratories, or x-ray equipment located in emergency room areas.

The quality control program should not be eliminated if the results indicate relatively stable equipment performance. The purpose of a quality control program is to control quality—something which cannot be done without periodic measurements of the performance of the equipment. If it is clear after many quality control checks that the equipment is quite stable, consider reducing the frequency of the quality control tests. However, the frequencies listed in the tables in this appendix should be considered as the *minimum* frequencies.

All of the quality control tests, plus other "acceptance tests," should be performed on the installation of new equipment, or the relocation of present equipment. These initial quality control tests provide the base-line operating levels for future quality control tests. Be careful not to assume that the system will be stable at the initial level. The equipment should be allowed to reach a stable level, within specifications, before establishing final operating levels.

Acceptance and initial quality control tests should be carried out with the equipment manufacturer's engineers present so that problems can be corrected as they are found. (About one week should be allowed for the acceptance and initial quality control tests of a radiographic and fluoroscopic room while a simple radiographic room should take one or two days.) However, initial test data should not be accepted as operating levels if the data indicate the equipment does not meet the vendor's specifications or if the equipment performance is not the same as that of similar equipment. In addition, the acceptance and quality control tests should be repeated at least one month before the end of the equipment warranty period to allow time for the manufacturer to correct problems that may have developed during the initial use of the equipment.

The appropriate quality control tests should be performed after equipment service or preventive maintenance. Both the quality of the images produced and patient safety and exposure should be evaluated. The quality control program should be responsible for verifying the integrity of the equipment *before* the service engineer leaves and, if at all possible, before the equipment is used for patient examinations.

Much modern imaging equipment is computer based or controlled. Consequently, it is essential to carry out acceptance tests after the installation of any software upgrades, especially in systems where the computer is used to adjust exposure or image quality factors.

Quality control tests should also be used in troubleshooting problems. For example, if a radiographic room is producing consistently light images, then the quality control tests can determine whether the problem is caused by faulty mA, kVp, or exposure timer calibration or by improper technique selection by the technologist using the room. In the case of faulty calibration the quality control tests can assist the service engineer and reduce the time required to correct the problem; in the case of improper technique selection the tests will eliminate the need for a costly visit by the service engineer.

In summary, the quality control tests are really much more than just periodic tests. The quality control tests can contribute to:

1. Acceptance testing of new or relocated equipment;
2. Acceptance testing of new or revised software;
3. Verification of equipment integrity after service or preventive maintenance;
4. Troubleshooting equipment problems;
5. Periodic testing of equipment to assist in maintaining the quality of the equipment output.

TABLE A.1—*Photographic quality control (Section 6)*

Test	Section number	Essential or desirable	Test device	Suggested performance criteria	Minimum frequency
Film and chemical storage	6.1.1	Essential	Visual inspection, thermometer, hygrometer	Fumes? Radiation? 65 ± 5 °F 50% ± 10% Humidity	Monthly
Darkroom conditions	6.1.2	Essential	Visual inspection, thermometer, hygrometer	Clean? 70 ± 5° 50% ± 10% Humidity	Monthly
Darkroom fog	6.1.3	Essential	Visual inspection, film, cassette, step wedge. Opaque material	<0.05 increase in density in 2 min	Semiannually
Manual processing	6.1.4				
Timer and thermometer		Essential	Comparison: timer and thermometer	Timer—± 5% Thermometer—± ½°F	Monthly
Chemicals		Essential	Sensitometer, densitometer, control emulsion	B+F + 0.05 Mid density ± 0.15 Density difference ± 0.15	Daily or before processing any films
Processor sensitometric evaluation	6.2.4	Essential	Sensitometer, Densitometer, Control emulsion	B+F + 0.05 Mid density ± 0.10 Density difference ± 0.10	Daily—before processing any film

TABLE A.1—*Photographic quality control (Section 6) (cont'd)*

Test	Section number	Essential or desirable	Test device	Suggested performance criteria	Minimum frequency
Tank level checks clean-up films, clean cross-overs		Essential	Visual inspection, Clean-up films	Full tanks, No scratches on films, Clean cross-overs	Daily
Cleaning and preventive maintenance		Essential	As suggested by manufacturer	As indicated by manufacturer	Manufacturer's instructions
Fixer	6.2.5				
Replenishment rate		Essential	Visual inspection	± 5%	Daily
Flow meter accuracy		Essential	Stop watch and graduated cylinder	± 5%	Quarterly
Film washing	6.2.6				
Wash water flow rate		Essential	Visual inspection of water flow meter	± 10%	Daily
Film fixer retention		Essential	Fixer retention test kit	$< 2\ \mu g/cm^2$ retained thiosulfate	Semiannually
Processor transport time	6.2.7	Essential	Stop watch	± 3%	Annually
Developer temperature		Essential	Thermometer built into processor	± 0.5°F	Daily
Wash water temperature		Essential	Thermometer built into processor	± 5.0°F	Daily
Built-in developer thermometer accuracy		Essential	Calibrated thermometer	± 0.5°F	Monthly

Developer recirculation filter	6.2.8	Essential	As suggested by manufacturer	As indicated by manufacturer	Manufacturer's instructions
Water filters		Essential	Visual inspection of flow meter	Change when flow rate decreases by more than 10%	Daily
Replenishment rate		Essential	Visual inspection	± 5%	Daily
Flow meter accuracy		Essential	Stop watch and graduated cylinder	± 5%	Quarterly
Daylight systems	6.3.2	Essential	As suggested by manufacturer	As indicated by manufacturer	Manufacturer's instructions
Processor stand-by units (verify function)	6.3.4	Essential	Visual inspection	As indicated by manufacturer	Daily
Automatic chemical mix system	6.3.5	Essential	As suggested by manufacturer	As indicated by manufacturer	Manufacturer's instructions
Silver recovery efficiency	6.3.3	Desirable	Silver test paper, direct reading device, or Hospital laboratory	± 10% of estimated weight	Quarterly

TABLE A.2—*Radiographic quality control (Section 7)*

Test	Section number	Essential or desirable	Test device	Suggested performance criteria	Minimum frequency
Filtration (HVL)	7.1.1	Essential	Dosimeter, type 1100 aluminum sheets, semi-log paper	Table 7.1	Annually
Light field and x-ray field alignment	7.1.2	Essential	Alignment template or nine pennies and tape measure	± 2% of source-to-image distance	Semi-annually
Automatic collimation or positive beam limitation and accuracy of x-y scales		Essential	Alignment template or nine pennies and tape measure	± 3% of source-to-image distance	Semi-annually
X-ray beam, bucky motion and centering	7.1.3	Essential	Homogeneous phantom and lead strips	Lead strips should be centered. Density uniform to ± 0.10 perpendicular to anode-cathode axis	Annually

X-ray beam perpendicularity, and SID indicator accuracy		Essential	Perpendicularity test tool and tape measure	Perpendicularity accuracy provided by tool manufacturer. SID indicator should be within ± 2% of measured value.	Annually
Focal spot size	7.1.4	Essential	Pinhole camera, lead star pattern, or slit	Table 7.2	Acceptance test
Visual checks	7.1.5	Essential	Visual check list	Pass-fail	Annually
Mechanical and electrical safety checks	7.1.6	Essential	Section 20	Section 20	Annually
Overload protection	7.2.1	Essential	Single exposure rating chart	Prevent exposures that exceed 80% of tube's maximum rated load	Annually
kVp	7.2.2	Essential	kVp cassette or direct reading kVp device	± 5%; less over limited range, *e.g.*, ± 2 kVp for 60 to 100 kVp	Annually
Exposure timers	7.2.3	Essential	Timing device	Single phase, Table 7.3; Three phase, ± 5%	Annually

TABLE A.2—*Radiographic quality control (Section 7) (cont'd.)*

Test	Section number	Essential or desirable	Test device	Suggested performance criteria	Minimum frequency
mR/mAs	7.2.5	Essential	Dosimeter, homogeneous phantom	± 10%	Annually
Linearity	7.2.6	Essential	Dosimeter	± 10% over clinical range	Annually
Exposure reproducibility	7.2.7	Essential	Dosimeter	± 5%	Annually
Phototimers	7.2.8				
Abbreviated tests Sensor panel function	7.2.8	Essential	Lead sheets and dosimeter	± 10% in exposure	Semi-annually
kVp correction circuit			Homogenous phantom	Density of 1.20 ± 0.30	
Proper exposure at various mA stations			Homogeneous phantom and dosimeter	± 10% in Exposure	
Proper exposure for various field sizes			Homogeneous phantom	Density of 1.20 ± 0.10	
Phototimer reproducibility			Homogeneous phantom and dosimeter	± 5% in exposure	

Density control function			Homogeneous phantom and dosimeter	Steps of 25% in exposure, verify button function, *i.e.*, + gives increase, − gives decrease	
Complete tests	7.2.8	Essential			Annually
All of "abbreviated tests" plus—					
Sensor panel location			Lead sheets	Pass-fail	
Minimum exposure time			Exposure timing device	< 10 ms	
Back-up exposure time			Exposure timing device and lead sheet	< 600 mAs	
Proper exposure with change in patient size			Homogeneous phantom	Density of 1.20 ± 0.30	
Grid uniformity Bucky grids	7.3.1	Essential	Homogeneous phantom	Uniform films, no grid lines, density of 1.20 ± 0.10 perpendicular to anode-cathode axis	Annually

TABLE A.2—*Radiographic quality control (Section 7) (cont'd.)*

Test	Section number	Essential or desirable	Test device	Suggested performance criteria	Minimum frequency
Grid cassettes and clip-on grids	7.3.1	Essential	Homogeneous phantom	Uniform films, density of 1.20 ± 0.10 perpendicular to anode-cathode axis	Semi annually
Grid alignment	7.3.2	Essential	Homogeneous phantom	Uniform films, density of 1.0 ± 0.10 perpendicular to anode-cathode axis	Annually
Screen-film-cassette speed matching	7.4.2	Essential	Standard (comparison) cassette	Densities within ± 0.05 for all cassettes used in one area	Annually
Screen-film contact	7.4.3	Essential	Coarse copper mesh	No significant areas of poor contact	Annually

Exposure per film	7.5.1	Essential	Homogeneous phantom and dosimeter	Film density of 1.20 ± 0.15 for AP lumbar spine technique and appropriate phantom. Exposure for AP lumbar spine in 100 to 160 μC kg^{-1} range or less	Every quality control check
Matching images and exposures	7.5.2	Essential	Homogeneous phantom and dosimeter	Film densities within ± 0.15 of average for all rooms. Entrance exposures within ± 10% for identical rooms	Every quality control check
X-ray output waveform	7.2.4	Desirable	X-ray detector and oscilloscope	Check for spikes, aberrant wave shapes, etc.	Annually

[a]100 μC kg^{-1} is equal to 400 mR.

TABLE A.3—*Fluoroscopic and cine quality control (Section 8)*

Test	Section number	Essential or desirable	Test device	Suggested performance criteria	Minimum frequency
X-ray tubes, collimators, and generators	8.1				
All indicated tests		Essential	See appropriate sections	See appropriate sections	Semi-annually
Maximum fluoroscopic exposure rates	8.2.1	Essential	Lead sheets and dosimeters	≤1.3 mC kg^{-1}[a]/min for manual systems ≤2.6 mC kg^{-1}/min[a] for automatic exposure control systems	Semi-annually
Standard fluoroscopic exposure rates	8.2.2	Essential	Homogeneous phantom and dosimeter	0.5 to 0.8 mC kg^{-1}[a]/min, 6-inch mode, without grid; 0.4 to 0.7 mC kg^{-1}[a]/min, 9-inch mode, without grid. Automatic exposure control should set 80 to 90 kVp	Semi-annually

Spot film and spot film camera exposures	8.2.3	Essential	Homogeneous phantom and dosimeters	13 to 50 nC kg^{-1} [a]/image at intensifier; film density of 1.20 ± 0.15 See Table 8.1	Semi-annually
Cine film exposure	8.2.4	Essential	Homogeneous phantom and dosimeter	Approx. 4 nC kg^{-1}[a]/frame at intensifier for 9-inch mode; approx. 7 nC kg^{-1}[a]/frame at intensifier for 6-inch mode. See Table 8.2	Semi-annually
Automatic brightness, exposure, and gain control systems	8.3	Essential	Homogeneous phantom and dosimeter	ABC-AEC systems should function similar to same installations and other similar systems. AGC should be able to compensate from 3 to 9 inches of acrylic	Semi-annually

TABLE A.3—*Fluoroscopic and cine quality control (Section 8) (cont'd.)*

Test	Section number	Essential or desirable	Test device	Suggested performance criteria	Minimum frequency
Fluoroscopic, spot film, and cine image size and beam limitation	8.4	Essential	Radiographically opaque template, direct exposure x-ray film	Displayed diameter not less than 1 cm smaller than specified diameter. Error between beam size and image size should be no greater than 3% of SID for all modes and at any tower height	Semi-annually
Fluoroscopic, spot film, and cine resolution and distortion	8.5	Essential	High and low contrast resolution patterns, homogeneous phantom, distortion gird	See Table 8.3, distortion symmetric, same for fluoroscopic, spot film, and cine images	
Radiographic/ Fluoroscopic					Semi-annually
Special procedure labs					Semi-annually

Cardiac catheterization labs					Semi-annually (Each case)
Cine projectors	8.9	Essential	SMPTE cine test film	Resolve all resolution elements in image, minimal jitter, clean lenses, prisms, and projection surface, projection bulb clean without metallic deposits	Semi-annually
Image lag	8.6	Desirable	Lag shutter, storage oscilloscope and camera	See Table 8.4	Semi-annually
Flare	8.7	Desirable	Lead disc, video waveform monitor	See Table 8.5	Semi-annually
Where low contrast image is important					Quarterly
Relative conversion factor	8.8	Desirable	Dosimeter, radiometer	Look for changes over time indicating deterioration of intensifier	Semi-annually

[a] 0.26 mC kg^{-1} = 1R; 0.26 mC kg^{-1} = 1μR.

TABLE A.4—*Mobile radiographic, capacitor discharge, and fluoroscopic systems quality control (Section 9)*

Test	Section number	Essential or desirable	Test device	Suggested performance criteria	Minimum frequency
Mobile radiographic units	9.1				
Batteries (completely discharged, fully charged and serviced)		Essential	As suggested by manufacturer	As indicated by manufacturer	Annually or manufacturer's instructions
All applicable tests		Essential	See appropriate sections	See appropriate sections	Annually
Capacitor discharge radiographic systems	9.2	Essential	See appropriate sections	See appropriate sections. kVp-acceptance test value becomes operating level rather than indicated kVp	Annually
Mobile fluoroscopic systems					
All applicable tests including tests of analog and digital video recording systems.	9.3	Essential	See appropriate sections	See appropriate sections	Semi-annually

TABLE A.5—*Quality control tests for conventional tomography (Section 10)*

Test	Section number	Essential or desirable	Test device	Suggested performance criteria	Minimum frequency
Section level	10	Essential	Tomographic phantom	± 5 mm	Annually
Level incrementation	10	Desirable	Tomographic phantom	± 2 mm	Annually
Section thickness	10	Essential	Tomographic phantom	To be established for the particular unit	Annually
Exposure angle	10	Desirable	Tomographic phantom	± 5 degrees for wide angle tomography; less for small angle tomography	Annually
Exposure uniformity and pattern	10	Desirable	Tomographic phantom	Qualitative evaluation	Annually
Spatial resolution	10	Essential	Tomographic phantom	40 mesh or better	Annually
Patient exposure	10	Essential	Radiation dosimeter	To be established for the particular unit; see Table 10.1	Annually

TABLE A.6—*Quality control tests for mammographic equipment (Section 11)*

Test	Section number	Essential or desirable	Test device	Suggested performance criteria	Minimum frequency
kVp accuracy	11	Essential	Mammographic kVp device	± 2 kVp	Semi-Annually
Entrance exposure	11	Essential	Low-energy ionization chamber	± 10 %	Semi-Annually
Mammographic low and high contrast resolution	11	Essential	Resolution phantom	No noticable deterioration in performance	Semi-Annually

TABLE A.7—*Dental radiography quality control (Section 12)*

Test	Section number	Essential or desirable	Test device	Suggested performance criteria	Minimum frequency
Test film	12.2.1	Essential	Film, CDRH device	± 2 optical density steps	Daily
Test radiograph	12.2.1	Essential	Film	Visual	Daily
Retake log	12.2.2	Essential			Daily
Film processing	12.2.4	Essential	Film, sensitometer, densitometer	< ± 0.1 density	Daily
Operation of darkroom	12.2.3	Essential			Quarterly
Cassette and Screens	12.2.5	Essential	Film, wire mesh	Visual	Annually
Viewboxes	12.2.6	Desirable	Light meter		Annually
X-ray unit					
leakage radiation	12.2.7	Essential	Survey meter	< 26 μC kg^{-1}[a]/h at 1 m	Annually
source-end of cone	12.2.7	Essential		> 4 in. (< 50 kVp) > 7 in. (> 50 kVp)	Annually
beam alignment and collimators	12.2.7	Essential	Film	< 2¾ in. (end of cone)	Annually
filtration (HVL)	12.2.7	Essential	Type 1100 A1 filters, ion chamber	See Table 7.1	Annually
timer	12.2.7	Essential	Spinning top, film		Annually
exposure switch	12.2.7	Essential			Annually
radiation exposure	12.2.7	Essential	Calibrated ion chambers	Range of acceptable exposures	Annually

[a]26 μC kg^{-1} = 100 mR.

TABLE A.8—*Quality control test for special procedures equipment (Section 13)*

Test	Section number	Essential or desirable	Test device	Suggested performance criteria	Minimum frequency
Film changer screen-film contact	13	Essential	Wire mesh	No significant difference between static and dynamic conditions	Semi-Annually
Low and high contrast resolution	13	Essential	Fluoroscopic resolution test device	No significant difference between static and dynamic conditions	Semi-Annually
Optical density of films over duration of filming run	13	Essential	Fluoroscopic phantom	Optical density difference $< \pm$ 0.2	Semi-Annually

Cinefluorographic exposure rates	13	Essential	Fluoroscopic phantom and ionization chamber	Approx. 2.6 to 5 nC/kg[a]/frame at intensifier for 23 cm mode; Approx. 5 to 8 nC/kg[a]/frame at intensifier for 15 cm mode. (see Table 8.2)	Semi-Annually
Cinefluorographic low and high contrast resolution	13	Essential	Fluoroscopic resolution test device	No degradation from fluoroscopic measurements	Semi-Annually
Ancillary special procedures equipment	13	Essential	Recommendations of equipment manufacturer	Recommendations of equipment manufacturer	Recommendations of equipment manufacturer

[a]2.6 nC kg^{-1} = 10 μR.

TABLE A.9—*Quality control tests for CT scanner (Section 14)*

Test	Section number	Essential or desirable	Test device	Suggested performance criteria	Minimum frequency
CT number calibration	14	Essential	20 cm diameter phantom[a]	Air: −1000 ± 3 CT numbers Water: 0 ± 1.5 CT numbers	Monthly
CT number constancy	14	Desirable	20 cm diameter phantom[a]	Value and std. dev. for water relatively constant	Daily
Hard copy output and visual display	14	Essential	"standard" image stored on disk (see Section 19.3)	Luminance & contrast not significantly different	Daily
Low contrast resolution	14	Essential	Low contrast phantom	0.5 cm holes	Monthly
CT number uniformity	14	Essential	20 cm diameter phantom[a]	variation ± 5 CT numbers among mean of 100 pixels	Monthly
Patient dosimetry	14	Essential	Dosimetry phantom	± 20%	Semi-Annually
Table position	14	Essential	Ruler	± 2 mm	Semi-Annually
Table indexing	14	Essential	Ruler or pre-packaged film	± 0.5 mm for each increment	Semi-Annually
Table backlash	14	Essential	Ruler or pre-packaged film	± 1 mm	Semi-Annually

CT number dependence on slice thickness	14	Essential	20 cm diameter phantom[a]	mean ± 3 CT numbers ave. over 100 pixels	Semi-Annually
Dependence of CT number on phantom size	14	Desirable	5 cm to 30 cm diameter phantom[a]	± 20 CT numbers	Semi-Annually
Accuracy of scout localization view	14	Essential	Small object in phantom	± 1 mm	Annually
Accuracy of distance measurements	14	Essential	1 cm spaced holes	± 1 mm	Annually
High contrast resolution	14	Desirable	High contrast phantom	0.1 cm holes	Monthly
Distortion of video monitor	14	Desirable	1 cm spaced holes	± 1 mm anywhere on image projection to life size	Monthly
Sensitivity profile	14	Desirable	45° wire in phantom	FWHM within 1 mm of nominal (5–15 mm) and within 0.5 mm (< 5 mm)	Monthly
Noise characteristics	14	Desirable	20 cm diameter phantom[a]	Std deviation of CT numbers (mAs)-½	Semi-Annually
Dependence of CT number on phantom position	14	Desirable	20 cm diameter phantom[a]	± 5 CT numbers	Annually
Dependence of CT number on algorithm	14	Desirable	20 cm diameter phantom[a]	± 3 CT numbers	Annually

[a]Water filled or water equivalent solid material.

TABLE A.10—*Digital imaging systems quality control (Section 15)*

Test	Section number	Essential or desirable	Test device	Suggested performance criteria	Minimum frequency
Digital subtraction angiographic imaging systems	15.1				
Fluoroscopic and conventional film imaging portions of system		Essential	See appropriate sections	See appropriate sections	Semi-annually
Digital imaging portion of system		Essential	Patient equivalent phantom with removable simulated iodine-filled vessels, step wedge, low contrast resolution pattern, mesh pattern, dosimeters	Low contrast resolution 1.6 c/mm for 6-inch and 1.2 c/mm for 9-inch intensifier; Other tests—similar results to acceptance tests and similar pieces of equipment	Quarterly
Visual (video) display and hard copy camera		Essential	SMPTE test pattern	See Section 19.3	Daily

TABLE A.11—*Nuclear medicine quality control (Section 16)*

Test	Section number	Essential or desirable	Test device	Suggested performance criteria	Minimum frequency
Radiation Calibrator					
Zero setting	16.2	Essential			Daily
Background setting	16.2	Essential			Daily
Test setting	16.2	Essential			Daily
Precision	16.2.1	Essential	^{137}Cs source	± 5%	Daily
Relative response to reference source	16.2.2	Essential	^{57}Co, ^{137}Cs and ^{133}Ba sources	± 2–5%	Quarterly
Linearity response	16.2.3	Essential	^{99m}Tc eluant, lead filters	± 5%	Quarterly
Accuracy	16.2.4	Essential	^{57}Co, ^{137}Cs and ^{133}Ba standards	± 5%	Annually
Geometry	16.2.5	Desirable	^{99m}Tc liquid	± 2%	Bi-annually
Scintillation Spectrometer					
Pulse height analyzer	16.3	Essential	^{137}Cs source	Voltage or gain adjust	Daily
Background	16.3.4	Essential		$< \pm 3\sigma$	Daily
Precision	16.3.5	Essential	^{137}Cs source	$< \pm 3\sigma$	Daily
60-cycle	16.3.2	Essential	60 cycle pulse signal	3600 ± 1 or 2 counts	Weekly
Chi-square test	16.3.6	Essential	^{137}Cs source	$0.1<p<0.9$	Quarterly

TABLE A.11—*Nuclear medicine quality control (Section 16) (cont'd.)*

Test	Section number	Essential or desirable	Test device	Suggested performance criteria	Minimum frequency
Energy calibration	16.3.7	Essential	^{137}Cs source	Voltage or gain adjust	Quarterly
Energy resolution	16.3.8	Essential	^{137}Cs source	8–9% solid crystal 10–12% well crystal	Annually
Linearity	16.3.9	Essential	^{99m}Tc, ^{131}I, ^{137}Cs sources	± 2 keV	Annually
Zero offset	16.3.9	Essential	^{99m}Tc, ^{131}I, ^{137}Cs sources	± 2 keV	Annually
Count rate effects	16.3.10	Essential	^{99m}Tc liquid (high activity), paired sources	correction	Annually
Nonimaging Scintillation Systems					
Precision	16.4.1	Essential	^{137}Cs Source	$< \pm 3\sigma$	Daily
Geometry	16.4.2	Essential	liquid source	correction factor	Bi-annually
Rectilinear Scanners					
Precision	16.5.1	Essential	^{137}Cs flood Source	$< \pm 3\sigma$	Daily
Density calibration	16.5.2	Essential	Point source, pulse generator	Within ± 0.2 density	Weekly

Contrast enhancement	16.5.3	Essential	Step wedge	Compare with baseline O.D. vs count density	Quarterly
Collimator spatial resolution	16.5.5	Desirable	Point source	Compare 50% response	Annually
Collimator depth of focus	16.5.6	Desirable	Point source	Compare 50% response	Annually
Scintillation Cameras					
Uniformity	16.6.1	Essential	^{99m}Tc or ^{57}Co Flood or point source	± 6–7% or computer corrected	Daily
Linearity	16.6.2	Essential	Flood or point source; bar or hole phantom	Visual	Weekly
Resolving power	16.6.2	Essential	Same as above	Visual	Weekly
Relative sensitivity	16.6.3	Essential	Flood or point source	± 10%	Weekly
Count rate characteristics	16.6.4	Essential	Different source activities	Input count rate for 20% loss	Semi-annually
Energy resolution	16.6.5	Essential	^{99m}Tc or ^{57}Co point source	Minimum of 50 channels per FWHM	Annually
System spatial resolution	16.6.6	Desirable	^{99m}Tc line sources, scatter material	Comparison with acceptance value	Annually
Imaging Accessories					
Multiformat camera	16.7.1	Essential	Bar or hole phantom	See Section 19	

TABLE A.11—*Nuclear medicine quality control (Section 16) (cont'd.)*

Test	Section number	Essential or desirable	Test device	Suggested performance criteria	Minimum frequency
Video tape systems	16.7.2	Essential		See Section 19	
Single Photon Emission Computed Tomography					
Uniformity	16.8.1	Essential	Flood source	< ± 1% corrected	Daily
Center of rotation	16.8.2	Essential	Point source	< ± 0.5 pixels (< ± 2 mm)	Weekly
Pixel sizing	16.8.3	Essential			Weekly
Table-camera	16.8.4	Essential		Within ± 2 mm	Weekly
Spatial resolution	16.8.5	Desirable	Line sources, scattering medium, high or medium sensitivity collimator		Annually
Phantoms	16.8.6	Desirable			
Camera-computer interface	16.8.7	Desirable	Point source		Annually

TABLE A.12—*Ultrasound quality control (Section 17)*

Test	Section number	Essential or desirable	Test device	Suggested performance criteria	Minimum frequency
Depth calibration accuracy	17.1	Essential	Phantom or test object	± 1%	Monthly
Digital caliper accuracy	17.1	Essential	Phantom or test object	± 1% vertical ± 3% horizontal	Monthly
Compound scan misregistration	17.1	Essential	Phantom or test object	5 mm maximum separation	Quarterly
Externally referenced measurement accuracy	17.1	Essential	Phantom or test object	Tolerance varies with the clinical need	Annually
System sensitivity	17.1	Essential	Tissue-mimicking phantom	Max. visualization depth within ± 1 cm	Monthly
Gray scale display and photography	17.1	Essential	Tissue phantom/ patient image	Same gray bars visualized; All parenchymal scatterers detected	Daily
M-mode depth calibration and Time markers	17.3	Essential	Phantom or test object	± 1% depth calibration; time markers ± 10%	Quarterly
Spatial resolution	17.2	Desirable	Phantom		Annually
Gray scale dynamic range	17.2	Desirable	Gray scale phantom; Electronic burst generator	Within ± 5 dB	Annually
Air filters	17.5	Essential	Examination	Clean	Monthly
Cables	17.5	Essential	Examination	Intact	Monthly

TABLE A.13—*Video imaging systems quality control (Section 19)*

Test	Section number	Essential or desirable	Test device	Suggested performance criteria	Minimum frequency
Video signal levels and line terminations	19.1	Essential	Video waveform monitor or oscilloscope	75-ohm termination at *end* of video cable; video signal—± 5% of peak-to-peak voltage.	Semi-annually
Television monitors	19.2	Essential	Video signal generator	All 10% steps visible, minimal distortion, resolution as specified by manufacturer	Semi-annually
Hard copy cameras and visual displays	19.3	Essential	SMPTE test pattern	Mid-density ± 0.15, film and visual display should give similar appearing images, 5% and 95% patches should be visible on film and visual display. Resolution should be consistent.	Daily

Video tape, disc, and digital recorders	19.4	Essential	Video signal generator, SMPTE video test tapes, video waveform monitor, high & low contrast x-ray resolution patterns	All 10% steps visible, minimal distortion, resolution as specified by manufacturer, drop-outs and jitter minimal, some increase in noise will be apparent in gray scale, some (minimal) loss in contrast between x-ray (fluoroscopic) and recorded image should be anticipated	Semi-annually

References

AADR (1983). American Academy of Dental Radiology. "Recommendations for quality assurance in dental radiography," Oral Surgery **55,** 421–426.

AAPM (1978). American Association of Physicists in Medicine. *Basic Quality Control in Diagnostic Radiology,* AAPM Report No. 4 (American Association of Physicists in Medicine, New York).

ACNP (1984). American College of Nuclear Physicians. *Initial Testing and Quality Control for Radionuclide Dose Calibrators* (American College of Nuclear Physicians, Washington).

Adams, R. (1984). "Suggested revision of NEMA standards," J. Nucl. Med. **25,** 814–816.

Addison, S. J., Hendee, W. R., Whitaker, F. M. and Rossi, R. P. (1978). "Diagnostic x-ray survey procedures for fluoroscopic installations—Part III, Cinefluorographic units," Health Phys. **35,** 845–850.

AIUM (1973). American Institute of Ultrasound in Medicine. *Standard Specification of Echoscope Sensitivity and Noise Level Including Recommended Practice for Such Measurements* (American Institute of Ultrasound in Medicine, Bethesda, Maryland).

AIUM (1974). American Institute of Ultrasound in Medicine. *The AIUM 100 mm Test Object and Recommended Procedures for Its Use* (American Institute of Ultrasound in Medicine, Bethesda, Maryland).

AIUM/NEMA (1981). American Institute of Ultrasound in Medicine/National Electrical Manufacturers Association. *AIUM/NEMA Safety Standard for Diagnostic Ultrasound* (American Institute of Ultrasound in Medicine, Bethesda, Maryland).

AIUM/NEMA (1985). American Institute of Ultrasound in Medicine/National Electrical Manufacturers Association. *AIUM/NEMA Performance Standard for Diagnostic Ultrasound,* Draft standard. (American Institute of Ultrasound in Medicine, Bethesda, Maryland).

Ansell, G., Tweedie, M. C. K., West, C. R., Evans, P. and Couch, L. (1980). "The current status of reactions to intravenous contrast media," Invest. Radiol. **15,** 6, 532–39.

ANSI (1981). American National Standards Institute. *Method for the Sensitometry of Medical and Dental X-Ray Film Used with Fluorescent Screens,* ANSI PH2.48-1981 (American National Standards Institute, New York).

ANSI (1982). American National Standards Institute. *Method of Sensitometry of Medical X-ray Screen-Film-Processing Systems,* ANSI PH2.43-1982 (American National Standards Institute, New York).

ANSI (1984). American National Standards Institute. *Filing Enclosures and Containers for Storage of Processed Films, Plates, and Paper,* ANSI PH1.53-1984 (American National Standards Institute, New York).

ARDRAN, G. M. AND CROOKS, H. E. (1968). "Checking diagnostic x-ray beam quality," Br. J. Radiol. **41,** 193–198.

AREEDA, J., CHAPMAN, D. VAN TRAIN, K., BIETENDORF, J., FRIEDMAN, J., BERMAN, D., WAXMAN, A. AND GARCIA, E. (1983). "Methods for characterizing and monitoring rotational gamma camera systems performance, emission computed tomography," in *Current Trends,* P. Esser, Ed. (Society of Nuclear Medicine, New York).

BANJAVIC, R. (1983). "Design and maintenance of a quality assurance program for diagnostic ultrasound equipment," Semin. Ultrasound **4,** 10–26.

BARNES, G. T., NELSON, R. E. and WITTEN, D. M. (1976). "A comprehensive quality assurance program: A report of four years' experience at the University of Alabama in Birmingham," Proc. Soc. Photo-Opt. Instrum. Eng. **96,** 19.

BEIR (1980). Committee on the Biological Effects of Ionizing Radiation. *The Effects on Populations of Exposure to Low Levels of Ionizing Radiation* (National Academy Press, Washington).

BELLON, E. M., MIVALDI, F. D. and WIESEN, E. J. (1979). "Performance evaluation of computed tomography scanners using a phantom model," Am. J. Roentgenol. **132,** 345–352.

BERGSTRÖM M. (1981). "Performance evaluation of scanners," pages 4212 to 4227 in *Radiology of the Skull and Brain: Technical Aspects of Computed Tomography,* Newton, T. H. and Potts, D. G., Eds. (C. V. Mosby, Co., St. Louis).

BIBERMAN, L. M. (1973). *Perception of Displayed Information* (Plenum Press, New York).

BIBERMAN, L. M. and NUDELMAN, S. (1971). *Photo-Electronic Imaging Devices—Vol. 1 Physical Processes and Methods of Analysis; Vol. 2 Devices and Their Evaluation* (Plenum Press, New York).

BOICE, J. D., Jr., LAND, C. E., and SHORE, R. E., NORMAN, J. E. and TOKUNAGA, M. (1979). "Risk of breast cancer following low-dose exposure," Radiology **131,** 589–597.

BOLLEN, R. (1984). "Speed of screen-film systems according to temperature," Proc. Soc. Photo-Opt. Instrum. Eng. **454,** 164–168.

BOOTE, E. and ZAGZEBSKI, J. (1985). "Performance tests of Doppler equipment with a tissue and blood mimicking phantom," J. Clin. Ultrasound (Supplement) **10,** 48.

BUCHSBAUM, W. H. (1975). *Fundamentals of Television* (Hayden Books, New York).

BUCHSBAUM, W. H. (1978). (Ed.) *Complete Handbook of Practical Electronic Reference Data* (Prentice-Hall, Englewood Cliffs, New Jersey).

BUDINGER, T. F., DERENZO, S. E., GULLBERG, G. T., GREENBERG, W. L. and HUESMAN, R. H. (1977). "Emission computer assisted tomography with photon and positron annihilation photon emitters," J. Comput. Assist. Tomogr. **1,** 131–145.

BURKHART, R. L. (1983). *Patient Radiation Exposure in Diagnostic Radiology Examination: An Overview,* HHS Publication (FDA) 83-8217 (Government Printing Office, Washington).

BURNETT, B. M., MAZZAFERRO, R. J. and CHURCH, W. W. (1975). *A Study of*

Retakes in Radiology Departments of Two Large Hospitals, DHEW Publication (FDA) 76-8016 (Government Printing Office, Washington).

CACAK, R. K. (1985). "Design of a quality assurance program: CT Scanners," pages 195 to 197 in *Selection and Performance Evaluation of Radiologic Equipment,* W. R. Hendee, Ed. (Williams and Wilkens, Baltimore, Maryland).

CACAK, R. K. and HENDEE, W. R. (1979). "Performance evaluation of a fourth generation computed tomography (CT) scanner," Proc. Soc. Photo-Opt. Instrum. Eng., **173,** 194–207.

CALICHECk (1984). Medi-Nuclear Corporation (Drayton Plains, Michigan).

CARSON, P. (1976). "Rapid evaluation of many pulse echo system characteristics by use of a triggered pulse burst generator with exponential decay," J. Clin. Ultrasound **4,** 259.

CARSON, P. and DUBUQUE, G. (1979). *Ultrasound Instrument Quality Control Procedure,* CRP Report No. 3. (Centers for Radiological Physics, Chevy Chase, Maryland).

CARSON, P. and ZAGZEBSKI, J. (1981). (Principal Authors). *Pulse Echo Ultrasound Imaging Systems: Performance Tests and Criteria,* AAPM Report 8. (American Institute of Physics, New York).

COHEN, G., KEREIAKES, J. G., PADIKAL, T. N., ASHARE, A. B. and SAENGER, E.L. (1976). "Quantitative assessment of field uniformity for gamma cameras," Radiology **118,**197–200.

CRABTREE, C. L. (1984). Personal Communication.

CRADDUCK, T. D. and FARRELL, T. J. (1984). "Uniformity correction and quality control in scintillation cameras," J. Nucl. Med. **25,** 1392–1394.

CURRY, T. S., DOWDEY, J. W. and MURRAY, R. C. (1984). *Christensen's Introduction to the Physics of Diagnostic Radiology,* 3rd ed. (Lea and Febiger, New York).

DRISCOLL, W. G. (1978). (Ed.) *Handbook of Optics* (McGraw-Hill, Inc., New York).

DUGGAN, T. and SIK, M. (1983). "Assessment of ultrasound scanners by acoustic signal injection," In *Ultrasound 82, Proceedings of the Third Meeting of the World Federation for Ultrasound in Medicine and Biology,* Lerski, R. and Morley, P., Eds. (Pergamon Press, New York).

EIA (1957). Electronics Industries Association. *Electrical Performance Standard-Monochrome Television Studio Facilities,* EIA Standard RS-170 (Electronics Industries Association, Washington).

EISENBERG, R. L. (1981). *Critical Diagnostic Pathways in Radiology: An Algorithmic Approach* (J. B. Lippincott Co., Philadelphia).

FDA (1976). Food and Drug Administration. *Quality Control for Scintillation Cameras,* HEW Publication (FDA) 76-8046 (Government Printing Office, Washington).

FDA (1984a). Food and Drug Administration. *Nationwide Evaluation of X-Ray Trends (NEXT) Eight Years of Data 1974–1981,* HHS Publication (FDA) 84-8229 (Government Printing Office, Washington).

FDA (1984b). Food and Drug Administration. *Quality Assurance in Nuclear Medicine:* Proceedings of an International Symposium and Workshop,

HHS Publication FDA 84-8224 (Government Printing Office, Washington).

FDA (1985a). Food and Drug Administration. *Evaluation of Radiation Exposure from Diagnostic Radiology Examinations: General Recommendations,* HHS Publication (FDA) 85-8246 (Government Printing Office, Washington).

FDA (1985b). Food and Drug Administration. *Evaluation of Radiation Exposure from Diagnostic Radiology Examinations—Technique/Exposure Guides for the Craniocaudal Projection in Mammography,* DHHS Publication (FDA) 85-8244 (Government Printing Office, Washington).

FDA (1985c). Food and Drug Administration. *Evaluation of Radiation Exposure from Diagnostic Radiology Examinations—Technique/Exposure Guides for the Dental Bitewing Projection,* HHS Publication (FDA) 85-8245 (Government Printing Office, Washington).

FDA (1986). Food and Drug Administration. Code of Federal Regulations, Title 21, Chapter 1, Subchapter J-Radiological Health, Parts 1000–1050 (Government Printing Office, Washington).

Frank, E. D., Gray, J. E. and Wilken, D. A. (1980). "Flood replenishment. A new method of processor control," Radiol. Technol. **52,** 271–275.

Friesinger, G. C., Adams, D. F., Bourassa, M. C., Carlsson, E., Elliott, L. P., Gessner, L. H., Greenspan, R. H., Grossman, W., Judkins, M. P., Ward-Kennedy, J. and Sheldon, W. C. (1983)."Optimal resources for examination of the heart and lungs: Cardiac catheterization and radiographic facilities," Circulation, **68,** 793A–930A.

Goldman, L. W. (1981). *Radiographic Film Processing Quality Assurance: A Self-Teaching Workbook,* HHS Publication (FDA) 81-8146 (Government Printing Office, Washington).

Goldman, L. W. and Beech, S. (1977). *Analysis of Retakes: Understanding, Managing and Using an Analysis of Retakes Program for Quality Assurance,* HEW Publication (FDA) 79-8097 (Government Printing Office, Washington).

Goldman, L. W. and Watkins, R. T. (1978). "Performance evaluation of commercially available sensitometers," J. Appl. Photog. Eng. **4,** 143–147.

Goldman, L., Vucich, J. J., Beech, S. and Murphy, W. L. (1977). "Automatic processing quality assurance program: Impact on a radiology department," Radiology **125,** 591–595.

Goldstein, A. (1980a). *Quality Assurance in Diagnostic Ultrasound. A Manual for the Clinical User,* HHS Publication (FDA) 81-8139 (Government Printing Office, Washington).

Goldstein, A. (1980b). *Quality Assurance in Diagnostic Ultrasound,* (American Institute of Ultrasound in Medicine, Bethesda, Maryland).

Gray, J. E. (1975). "Light fog on radiographic films. How to measure it properly," Radiology **115,** 225–227.

Gray, J. E. (1977). "Minimum requirements for film processing to minimize patient dose in an x-ray facility," page 47 in *Second Image Receptor Conference: Radiographic Film Processing,* DHEW Publication (FDA) 77-8036 (Government Printing Office, Washington).

GRAY, J. E. and SWEE, R. G. (1982). "The elimination of grids during intensified fluoroscopy and photofluorospot imaging," Radiology **144,** 426–429.

GRAY, J. E., STEVENS, E. C. and VUCICH, J. J. (1976). *Photographic Quality Assurance in Diagnostic Radiology, Nuclear Medicine, and Radiation Therapy: Volume 1, The Basic Principles of Daily Photographic Quality Assurance,* HEW Publication (FDA) 76-8043 (Government Printing Office, Washington).

GRAY, J. E., STEVENS, E. C. and VUCICH, J. J. (1977). *Photographic Quality Assurance in Diagnostic Radiology, Nuclear Medicine, and Radiation Therapy: Volume 2, Photographic Processing, Quality Assurance, and the Evaluation of Photographic Materials,* HEW Publication (FDA) 77-8018 (Government Printing Office, Washington).

GRAY, J. E., WINKLER, N. T., STEARS, J. and FRANK, E. D. (1983). *Quality Control in Diagnostic Imaging.* (University Park Press, Baltimore, Maryland).

GRAY, J. E., STEARS, J. G., LOPEZ, F. and WONDROW, M. A. (1984a). "Fluoroscopic imaging. Quantitation of image lag or smearing," Radiology **150,** 563–567.

GRAY, J. E., STEARS, J. G. and WONDROW, M. A. (1984b). "Quality control of video components and display devices," Proc. Soc. Photo-Opt. Instrum. Eng. **486,** 64–71.

GRAY, J. E., WONDROW, M. A., SMITH, H. C. and HOLMES, D. R. (1984c). "Technical considerations for cardiac laboratory high-definition video systems," Catheter. Cardiovasc. Diagn. **10,** 73–86.

GRAY, J. E., LISK, K. G., HADDICK, D. H., HARSHBARGER, J. H., OOSTERHOF, A. and SCHWENKER, R. (1985). "Test pattern for video displays and hard-copy cameras," Radiology **154,** 519–527.

GROB, B. (1975). *Basic Television* (McGraw-Hill, New York).

GROSSMAN, L. W., VAN TUINEN, R. J. and KEREIAKES, J. G. (1982). "Monitoring of xenon-133 charcoal trap efficiency using a GM survey instrument," J. Nucl. Med. **23**(5): P94. (Abstract of paper, 29th Annual Meeting Society of Nuclear Medicine).

HALL, A. and FLEMING, J. (1975). "A method for checking the registration of contact B-scanners," J. Clin. Ultrasound **3,** 51.

HALL, C. L. (1977). "Economic analysis of a quality control program,"Proc. Soc. Photo-Opt. Instrum. Eng. **127,** 271.

HALL, J. L., RILEY, R. L., SPIEGLER, P. and MOLER, C. L. (1978). "Is monitoring of bromide concentration important in automatic processing?" Appl. Radiol. May-June, **7,** 88–90.

HANSEN, G. (1969). *Introduction to Solid State Television Systems* (Prentice-Hall, Englewood, New Jersey).

HENDEE, W. R. and ROSSI, R. P. (1979). *Quality Assurance for Conventional Tomographic X-ray Units,* HEW Publication (FDA) 80-8096. (Government Printing Office, Washington).

HENDEE, W. R., ROSSI, R., SPITZER, V., BANJAVIC, R., CACAK, R. and IBBOTT, G. (1985). "Design of a quality assurance program," pages 182 to 195 in *Selection and Performance Evaluation of Radiologic Equipment,* Hendee, W.R., Ed. (Williams and Wilkens, Baltimore).

HILLMAN, B., ABRAMS, H. L., HESSEL, S. J., HERBERT, S., BENAZZI, R. B., and GERSON, D. E. (1979) "Simplifying radiological examinations. The urogram as a model," Lancet, **1,** 1068–1071.

HINE, G., PARAS, P. and WARR, C. (1977). *Measurement of the Performance Parameters of Gamma Cameras: Part I,* HEW Publication (FDA) 78-8049 (Government Printing Office, Washington).

HINE, G., PARAS, P., WARR, C. and ADAMS, P. (1979). *Measurement of the Performance Parameters of Gamma Cameras: Part II,* HEW Publication (FDA) 79-8049 (Government Printing Office, Washington).

HOLMES, D. R., Jr., SMITH, H. C., GRAY, J. E. and WONDROW, M. A. (1984). "Clinical evaluation of application of cardiac laboratory high-definition video systems," Catheter. Cardiovas. Diagn. **10,** 63–71.

IAEA (1984). International Atomic Energy Agency. *Quality Control of Nuclear Medicine Instruments,* IAEA-TECDOC 317 (International Atomic Energy Agency, Vienna).

ICHD (1983). Intersociety Commission for Heart Disease. "Optimal resources for examination of the heart and lungs: Cardiac catheterization and radiographic facilities," by the Examination of the Chest and Cardiovascular System Study Group including Friesinger, G. C., Adams, D. F., Bourassa, M. G., Carlsson, E., Elliot, L. P. Circulation, **68,** 893A–930A.

ICRP (1982). International Commission on Radiological Protection. *Protection of the Patient in Diagnostic Radiology,* ICRP Publication 34 (Pergamon Press, New York).

IEC (1985). International Electrotechnical Commission. *Methods of Measuring the Performance of Continuous-Wave Ultrasonic Doppler Diagnostic Equipment,* Draft Standard of the International Electrotechnical Commission. (American National Standards Institute, New York).

JAEGER, S. S., CACAK, R. K., BARNES, J. E. and HENDEE, W. R. (1978). "Optimization of xeroradiographic exposures," Radiology **128,** 217–222.

JASZCZAK, R. J., CHANG, L. T., STEIN, N. A. and MOORE, F. E. (1979). "Whole body single photon emission computed tomography using dual, large-field-of-view scintillation cameras," Phys. Med. Biol. **24,** 1123.

JARRITT, P. M., CULLUM, I. D., ELL, P. J. and KAHN, O. (1982). *Instrument and Imaging Protocols in Radionuclide Section Scanning.* (Chapman and Hall, London).

JUCIUS, R. A. and KAMBIC, G. X. (1977). *Applications in Medicine VI,* Proc. Soc. Photo-Opt. Instrum. Eng. **127,** 286–295.

KING, M. A., SCHWINGER, R. B., ESSER, P. D. RUDACK, E. J., SHUKLA, K. P., HARRELL, C. R., STEIDLEY, J. W., ALDERSON, P. O. AND DOHERTY, P. W. (1983). "Preliminary characterization of the properties of a new rotating SPECT imaging system, emission computed tomography," in *Current Trends,* P. Esser, Ed. (Society of Nuclear Medicine, New York).

LAWRENCE, D. J. (1973). "A simple method for processor quality control," Med. Radiog. Photog. **49,** 2–6 and 28.

LEACH, M. O., FLOWER, M. A., OTT, R. J. and WEBB, S. (1984). "The measurement of resolution in single photon emission computerized tomography," Phys. Med. Biol. (Letter to Editor) **29**(3), 282.

LEVI, C., GRAY, J. E., MCCULLOUGH, E. C. and HATTERY, R. R. (1982). "The

unreliability of CT numbers vs. absolute values," Am. J. Roentgenol. **139,** 443–447.

LEVY, L. B. and ESCAMILLA, R. (1979). "A study of retakes in diagnostic radiology at an army medical center," Appl. Radiol., July–Aug., **8,** 45–48, 123.

LITTLETON, J. T. (1970). "A phantom method to evaluate the clinical effectiveness of a tomographic device," Amer. J. Roentgenol. Radium Ther. Nuclear Med. **108,** 847–856.

MACEWAN, D. W. (1982). "Radiology workload system for diagnostic radiology: productivity enhancement studies," J. Canad. Assoc. Radiolog. **33,** 183–196.

MANNY, E. F. and BURKHART, R. L. (1985). *Measurement Techniques for Use with Technique/Exposure Guides,* HHS Publication (FDA) 85-8248 (Government Printing Office, Washington).

MASON-HING, L. R. (1985). *Fundamentals of Dental Radiography, 2nd ed.* (Lea and Febiger, Philadelphia, PA).

MCCULLOUGH, E. C. (1980). "Specifying and evaluating the performance of computed tomography (CT) scanners," Med. Phys. **7,** 291–296.

MCNEIL, B. J. and ABRAMS, H. L., Eds. (1986). *Brigham and Womens Hospital Handbook of Diagnostic Imaging* (Little, Brown and Company, Boston).

MITCHELL, M. D., KUNDEL, H. L., AXEL, L., and JOSEPH, P. M. (1986). "Agarose as a tissue equivalent phantom material for NMR imaging," Magnetic Resonance Imag., **1,** 135–141.

MOORE, M. M., CACAK, R. K. and HENDEE, W. R. (1981). "Multisegmented ion chamber for CT scanner dosimetry," Med. Phys. **8,** 640–645.

MOORE, R. J. (1981). "Photographic method for measurement of image intensifier tube contrast," Proc. Soc. Photo-Opt. Instrum. Eng. **273,** 168–176.

Moore, R. J. (1982). "In-the-field measurement of image intensifier tube contrast. Results, 1981," Proc. Soc. Photo-Opt. Instrum. Eng. **347,** 218–222.

NCRP (1973). National Council on Radiation Protection and Measurements. *Dental X-ray Protection,* NCRP Report No. 35 (National Council on Radiation Protection and Measurements, Bethesda, Maryland).

NCRP (1978). National Council on Radiation Protection and Measurements. *Instrumentation and Monitoring Methods for Radiation Protection,* NCRP Report No. 57 (National Council on Radiation Protection and Measurements, Bethesda, Maryland).

NCRP (1980). National Council on Radiation Protection and Measurements. *Mammography,* NCRP Report No. 66 (National Council on Radiation Protection and Measurements, Bethesda, Maryland).

NCRP (1981). National Council on Radiation Protection and Measurements. *Radiation Protection in Pediatric Radiology,* NCRP Report No. 68 (National Council on Radiation Protection and Measurements, Bethesda, Maryland).

NCRP (1982). National Council on Radiation Protection and Measurements. *Biological Effects of Ultrasound: Mechanisms and Clinical Implications,* NCRP Report No. 74 (National Council on Radiation Protection and Measurements, Bethesda, Maryland).

NCRP (1985a). National Council on Radiation Protection and Measure-

ments. *SI Units in Radiation Protection and Measurements,* NCRP Report No. 82 (National Council on Radiation Protection and Measurements, Bethesda, Maryland).

NCRP (1985b). National Council on Radiation Protection and Measurements. *A Handbook of Radioactivity Measurements Procedures,* 2nd ed., NCRP Report No. 58 (National Council on Radiation Protection and Measurements, Bethesda, Maryland).

NCRP (1986). National Council on Radiation Protection and Measurements. *Mammography—A Users Guide,* NCRP Report No. 85 (National Council on Radiation Protection and Measurements, Bethesda, Maryland).

NEMA (1984). National Electrical Manufacturers Association. *Measurement of Dimensions and Properties of Focal Spots of Diagnostic X-ray Tubes,* NEMA Standard Publication Number XR5-1974 (R-1984) (National Electical Manufacturers Association, New York.)

NEMA (1986). National Electrical Manufacturers Association. *Performance Measurements of Scintillation Cameras,* Standards Publication No. NU1-1980 (National Electrical Manufacturers Association, Washington).

NRC (1980). Nuclear Regulatory Commission. *Guide for the Preparation of Applications for Medical Programs,* Regulatory Guide 10.8 (Nuclear Regulatory Commission, Washington).

Pavlicek, W. A., Weinstein, M. A. and Modic, M. T. (1982). "Patient doses during digital subtraction angiography of the carotid arteries: Comparison with conventional angiography of the carotid arteries, Radiology **145,** 683–685.

Plunkett, M. B., Gray, J. E. and Kispert, D. B. (1985). "Radiation exposure from conventional and digital subtraction angiography of cerebral vessels," Am. J. Neuroradiol. **7,** 665.

Poznanski, A. K. and Smith, L. A. (1968). "Practical problems in processing control," Radiology **90,** 135–138.

Raff, U., Spitzer, V. M. and Hendee, W. R. (1984). "Practicality of NEMA performance specification measurements for user-based acceptance testing and routine quality assurance," J. Nucl. Med. **25,** 679–687.

Rao, G. U. V. (1966). "Influence of focus and off-focus radiation on radiographic detail (modulation transfer function) and patient exposure in diagnostic radiology," Report on contract #FAPH 76496. (Public Health Service, Washington).

Rao, G. U. V. (1974). "Influence of off-focus radiation on radiographic resolution and patient exposure," Appl. Radiol., May/June, **3,** 45–49.

Rossi, R. P. and Bromberg, N. (1982). "Evaluation of the contrast ratio of intensified fluoroscopic imaging systems," Proc. Soc. Photo-Opt. Instrum. Eng. **347,** 229–237.

Sandrik, J. M. (1984). "Video cameras for medical imaging," Proc. Soc. Photo-Opt. Instrum. Eng. **486,** 30–44.

Schwenker, R. P. (1979). "Film selection considerations for computed tomography and ultrasound video photography," *Application of Optical Instrumentation in Medicine VII* Proc. Soc. Photo-Opt. Eng. **173,** 75–80.

Shope, T. B., Gagne, R. M. and Johnson, G. D. (1981). "A method of describ-

ing the doses delivered by transmission x-ray computed tomography," Med. Phys. **8,** 488–495.

SMPTE (1983). Society of Motion Picture and Television Engineers. *Catalog of Cine and Video Test Materials.* (Society of Motion Picture and Television Engineers, Scarsdale, New York).

SMPTE (1986). Society of Motion Picture and Television Engineers. "SMPTE recommended practice—specifications for medical diagnostic imaging test pattern for television monitors and hard-copy recording cameras," RP 133-1986, SMPTE, J., June, 693–695.

STEARS, J. G., GRAY, J. E. and WINKLER, N. T. (1979). "Evaluation of pH monitoring as a method of processor quality control," Radiolog. Technol. **50,** 657–663.

STEARS, J. G., GRAY, J. E. WEBBLES, W. E. and FRANK, E. D. (1985). "X-ray waveform monitoring for radiographic quality control," Radiological Society of North America Annual Meeting, 1983, Radiol. Tech. **57,** 9–15.

SULEIMAN, O. H., SHOWALTER, C. K., KOUSTENIS, G. H. and HOTTE, E. (1982). *A Sensitometric Evaluation of Film-Chemistry-Processor Systems in the State of New Jersey,* HHS Publication FDA 82-8189 (Government Printing Office, Washington).

SULEIMAN, O. H., SHOWALTER, C. K., GROSS, R. E. and BUNGE, R. E. (1984). "Radiographic film fog in the darkroom," Radiology **151,** 237–238.

THOMAS, S. R., FRESHCORN, J. E., KRUGH, K. B., HENRY, G. C., KEREIAKES, J.G. and KAUFMAN, R. A. (1983). "Characteristics of extrafocal radiation and its potential significance in pediatric radiology," Radiology **146,** 793–799.

THOMAS, W. Jr. (1973). *SPIE Handbook of Photographic Science and Engineering* (John Wiley and Sons, New York).

TITUS, D. E. (1979a). *Flooded Replenishment Method for Cine Processing,* Publication No. MPA 7.236 (Eastman Kodak Company, Rochester, New York).

TITUS, D. E. (1979b). *Flooded Replenishment Method for Low Volume Industrial X-ray Processors,* Publication No. MPA 7.237 (Eastman Kodak Company, Rochester, New York).

TITUS, D. E. (1979c). *Flooded Replenishment System for Dedicated or Low Volume Kodak RP X-Omat Processors,* Publication No. MPA 7.235 (Eastman Kodak Company, Rochester, New York).

TROUT, E. D. and KELLEY, J. P. (1974). "The deterioration of x-ray fluoroscopic screens," Radiology **110,** 103–104.

UPTON, A. C., BEEBE, G. W. and BROWN, J. M. (1977). "Report of NCI ad hoc working group on the risks associated with mammography in mass screening for the detection of breast cancer," J. Natl. Cancer Inst. **59,** 481–493.

VAN TUINEN, R. J. and KEREIAKES, J. G. (1981). "Accurate assay of administered activity," pages 34 to 44 in *Radiation Safety in Nuclear Medicine: A Practical Guide,* HHS Publication FDA 82-8180 (Government Printing Office, Washington).

WEAVER, K. E. (1979). "Imaging factors and evaluation: Computed tomography scanning," in *The Physics of Medical Imaging Recording System*

Measurements and Techniques, Proceeding of the AAPM Summer School, Haus, A. G., Ed. (American Institute of Physics, New York).

WEAVER, K. E., WAGNER, R. and GOODENOUGH, D. J. (1975). "Performance considerations of x-ray tube focal spots," Proc. Soc. Photo-Opt. Instrum. Eng. **56,** 150–158.

WEAVER, K. E., BARONE, G. J. and FEWELL, T. R. (1978). "Selection of technique factors for mobile capacitor energy storage x-ray equipment," Radiology **128,** 223–228.

WEBB, S., FLOWER, M. A., OTT, R. J., LEACH, M. O. and INAMDAR, R. (1983). "The spatial resolution of a rotating gamma camera tomographic facility," Br. J. Radiol. **56,** 939–944.

Western Electric (1983). Western Electric Company, Inc. *Statistical Quality Control Handbook* (Western Electric Company, Inc., Indianapolis, Indiana).

WHEELER, J. (1983). "Long-term storage of videotape," J. Soc. Mot. Pict. Telev. Eng. **92,** 650–654.

WHITE, S. C., HOLLENDER, L. and GRATT, B. M. (1984). "Comparison of xeroradiographs and films for detection of periapical lesions," J. Dent. Res. **63**(6), 910–913.

WHO (1982). World Health Organization. *Quality Assurance in Nuclear Medicine* (World Health Organization, Geneva).

ZAGZEBSKI, J. (1980). "Ultrasound equipment acceptance tests," page 514 in *The Medical Physics of CT and Ultrasound: Tissue Imaging and Characterization,* Fullerton, G. and Zagzebski, J., Eds. AAPM Monograph 6. (American Institute of Physics, New York).

ZAGZEBSKI, J. (1983). "Instrument quality assurance," page 61 in *Textbook of Diagnostic Ultrasonography,* Hagen-Ansert, S., Ed. (CV Mosby, St. Louis, Missouri).

ZAGZEBSKI, J. and Madsen, E. (1983). "Performance measurements of manual and real-time scanners using a new tissue-mimicking phantom," in *Ultrasound '82, Proceedings of the Third Meeting of the World Federation for Ultrasound in Medicine and Biology,* Lerski, R. and Morley, P., Eds. (Pergamon Press, New York).

The NCRP

The National Council on Radiation Protection and Measurements is a nonprofit corporation chartered by Congress in 1964 to:

1. Collect, analyze, develop, and disseminate in the public interest information and recommendations about (a) protection against radiation and (b) radiation measurements, quantities, and units, particularly those concerned with radiation protection;
2. Provide a means by which organizations concerned with the scientific and related aspects of radiation protection and of radiation quantities, units, and measurements may cooperate for effective utilization of their combined resources, and to stimulate the work of such organizations;
3. Develop basic concepts about radiation quantities, units, and measurements about the application of these concepts, and about radiation protection;
4. Cooperate with the International Commission on Radiological Protection, the International Commission on Radiation Units and Measurements, and other national and international organizations, governmental and private, concerned with radiation quantities, units, and measurements and with radiation protection.

The Council is the successor to the unincorporated association of scientists known as the National Committee on Radiation Protection and Measurements and was formed to carry on the work begun by the Committee.

The Council is made up of the members and the participants who serve on the over sixty scientific committees of the Council. The scientific committees, composed of experts having detailed knowledge and competence in the particular area of the committee's interest draft proposed recommendations. These are then submitted to the full membership of the Council for careful review and approval before being published.

The following comprise the current officers and membership of the Council:

Officers

President	Warren K. Sinclair
Vice President	S. James Adelstein

Secretary and Treasurer	W. Roger Ney
Assistant Secretary	Carl D. Hobelman
Assistant Treasurer	James F. Berg

Members

Seymour Abrahamson
S. James Adelstein
Peter R. Almond
Edward L. Alpen
John A. Auxier
William J. Bair
Michael A. Bender
Bruce B. Boecker
John D. Boice, Jr.
Robert L. Brent
Antone Brooks
Thomas F. Budinger
Melvin W. Carter
Randall S. Caswell
James E. Cleaver
Fred T. Cross
Stanley B. Curtis
Gerald D. Dodd
Patricia W. Durbin
Joe A. Elder
Thomas S. Ely
Jacob I. Fabrikant
R. J. Michael Fry
Ethel S. Gilbert
Robert A. Goepp
Joel E. Gray
Arthur W. Guy
Eric J. Hall
Naomi H. Harley
William R. Hendee
Donald G. Jacobs
A. Everette James, Jr.
Bernd Kahn
Kenneth R. Kase
Charles E. Land
George R. Leopold
Ray D. Lloyd
Arthur C. Lucas
Charles W. Mays
Roger O. McClellan
James E. McLaughlin
Barbara J. McNeil
Thomas F. Meaney
Charles B. Meinhold
Mortimer L. Mendelsohn
Fred A. Mettler
William A. Mills
Dade W. Moeller
A. Alan Moghissi
Mary Ellen O'Connor
Andrew K. Poznanski
Norman C. Rasmussen
Wiliam C. Reinig
Chester R. Richmond
James S. Robertson
Marvin Rosenstein
Lawrence N. Rothenberg
Leonard A. Sagan
Robert A. Schlenker
William J. Schull
Roy E. Shore
Warren K. Sinclair
Paul Slovic
Lewis V. Spencer
William L. Templeton
Thomas S. Tenforde
J. W. Thiessen
John E. Till
Robert Ullrich
Arthur C. Upton
George L. Voelz
Edward W. Webster
George M. Wilkening
H. Rodney Withers
Marvin Ziskin

Honorary Members

Lauriston S. Taylor, Honorary President

Victor P. Bond
Reynold F. Brown
Austin M. Brues
George W. Casarett
Frederick P. Cowan
James F. Crow
Merrill Eisenbud
Robley D. Evans
Richard F. Foster
Hymer L. Friedell
Robert O. Gorson
John H. Harley
John W. Healy
Louis H. Hempelmann, Jr.
Paul C. Hodges
George V. LeRoy
Wilfrid B. Mann
Karl Z. Morgan
Robert J. Nelsen
Wesley Nyborg
Harald H. Rossi
William L. Russell
John H. Rust
Eugene L. Saenger
J. Newell Stannard
Roy C. Thompson
Harold O. Wyckoff

Currently, the following subgroups are actively engaged in formulating recommendations:

SC 1:	Basic Radiation Protection Criteria
SC 1-1:	Probability of Causation for Genetics
SC 1-2:	Risk Estimates for Radiation Protection
SC 3:	Medical X-Ray, Electron and Beam and Gamma-Ray Protection for Energies Up to 50 MeV (Equipment Performances and Use)
SC 16:	X-Ray Protection in Dental Offices
SC 18:	Standards and Measurements of Radioactivity for Radiological Use
SC 40:	Biological Aspects of Radiation Protection Criteria
SC 40-1:	on Atomic Bomb Survivor Dosimetry
SC 40-1A:	on Biological Aspects of Dosimetry of Atomic Bomb Survivors
SC 44:	Radiation Associated with Medical Examinations
SC 45	Radiation Received by Radiation Employees
SC 46:	Operational Radiation Safety
SC 46-2:	on Uranium Mining and Milling—Radiation Safety Programs
SC 46-3:	on ALARA for Occupationally Exposed Individuals in Clinical Radiology
SC 46-4:	on Calibration of Instrumentation
SC 46-5:	on Maintaining Radiation Protection Records
SC 46-6:	on Radiation Protection for Allied Health Personnel
SC 46-7:	on Emergency Planning
SC 46-8:	on Radiation Protection Design Guidelines for Particle Accelerators
SC 46-9:	on ALARA at Nuclear Power Plants
SC 46-10:	Assessment of Occupational Exposures from Internal Emitters
SC 47:	Instrumentation for the Determination of Dose Equivalent
SC 52:	Conceptual Basis of Calculations of Dose Distributions
SC 57:	Internal Emitter Standards
SC 57-2	on Respiratory Tract Model
SC 57-5:	on Gastrointestinal Models

SC 57-6:	on Bone Problems
SC 57-8:	on Leukemia Risk
SC 57-9	on Lung Cancer Risk
SC 57-10:	on Liver Cancer Risk
SC 57-12:	on Strontium
SC 57-14	on Placental Transfer
SC 57-15:	on Uranium
SC 59:	Human Radiation Exposure Experience
SC 63-I:	Radiation Exposure Control in a Nuclear Emergency
SC 63-II:	Radiation Exposure Control in a Nuclear Emergency
SC 63-II-1:	Public Knowledge About Radiation
SC 63-II-2:	Criteria for Radiation Instruments for the Public
SC 63-II-3:	on Exposure Criteria for Specialized Categories of the Public
SC 64:	Environmental Radioactivity and Waste Management
SC 64-6:	on Screening Models
SC 64-7:	on Contaminated Soil as a Source of Radiation Exposure
SC 64-8:	on Ocean Disposal of Radioactive Waste
SC 64-9:	on Biological Effects on Aquatic Organisms
SC 64-10:	on Low Level Waste
SC 64-11:	on Xenon
SC 65:	Quality Assurance and Accuracy in Radiation Protection Measurements
SC 66:	Biological Effects and Exposure Criteria for Ultrasound
SC 67:	Biological Effects of Magnetic Fields
SC 68:	Microprocessors in Dosimetry
SC 69:	Efficacy of Radiographic Procedures
SC 71:	Radiation Exposure and Potentially Related Injury
SC 74:	Radiation Received in the Decontamination of Nuclear Facilities
SC 76:	Effects of Radiation on the Embryo-Fetus
SC 77:	Guidance on Occupational and Public Exposure Resulting from Diagnostic Nuclear Medicine Procedures
SC 78:	Practical Guidance on the Evaluation of Human Exposures to Radiofrequency Radiation
SC 79:	Extremely Low-Frequency Electric and Magnetic Fields
SC 80:	Radiation Biology of the Skin (Beta-Ray Dosimetry)
SC 80-1:	on Hot Particles on the Skin
SC 81:	Assessment of Exposure from Therapy
SC 82:	Control of Indoor Radon

Study Group on Comparative Risk
Ad Hoc Group on Medical Evaluation of Radiation Workers
Ad Hoc Group on Video Display Terminals
Task Force on Occupational Exposure Levels

In recognition of its responsibility to facilitate and stimulate cooperation among organizations concerned with the scientific and related aspects of radiation protection and measurement, the Council has created a category of NCRP Collaborating Organizations. Organizations or groups of organizations that are national or international in scope and are concerned with scientific problems involving radiation quantities, units, measurements, and effects, or radiation protection may be admitted to collaborating status by the Council. The

present Collaborating Organizations with which the NCRP maintains liaison are as follows:

American Academy of Dermatology
American Association of Physicists in Medicine
American College of Medical Physics
American College of Nuclear Physicians
American College of Radiology
American Dental Association
American Industrial Hygiene Association
American Institute of Ultrasound in Medicine
American Insurance Association
American Medical Association
American Nuclear Society
American Occupational Medical Association
American Podiatric Medical Association
American Public Health Association
American Radium Society
American Roentgen Ray Society
American Society of Radiologic Technologists
American Society for Therapeutic Radiology and Oncology
Association of University Radiologists
Atomic Industrial Forum
Bioelectromagnetics Society
College of American Pathologists
Conference of Radiation Control Program Directors
Federal Communications Commission
Federal Emergency Management Agency
Genetics Society of America
Health Physics Society
Institute of Nuclear Power Operations
National Electrical Manufacturers Association
National Institute of Standards and Technology
Radiation Research Society
Radiological Society of North America
Society of Nuclear Medicine
United States Air Force
United States Army
United States Department of Energy
United States Department of Housing and Urban Development
United States Department of Labor
United States Environmental Protection Agency
United States Navy
United States Nuclear Regulatory Commission
United States Public Health Service

The NCRP has found its relationship with these organizations to be extremely valuable to continued progress in its program.

Another aspect of the cooperative efforts of the NCRP relates to the special liaison relationships established with various governmental organizations that have an interest in radiation protection

and measurements. This liaison relationship provides: (1) an opportunity for participating organizations to designate an individual to provide liaison between the organization and the NCRP; (2) that the individual designated will receive copies of draft NCRP reports (at the time that these are submitted to the members of the Council) with an invitation to comment, but not vote; and (3) that new NCRP efforts might be discussed with liaison individuals as appropriate, so that they might have an opportunity to make suggestions on new studies and related matters. The following organizations participate in the special liaison program:

Australian Radiation Laboratory
Commission of the European Communities
Commisariat a l'Energie Atomique (France)
Defense Nuclear Agency
Federal Emergency Management Agency
Japan Radiation Council
National Institute of Standards and Technology
National Radiological Protection Board (United Kingdom)
National Research Council (Canada)
Office of Science and Technology Policy
Office of Technology Assessment
United States Air Force
United States Army
United States Coast Guard
United States Department of Energy
United States Department of Health and Human Services
United States Department of Labor
United States Department of Transportation
United States Environment Protection Agency
United States Navy
United States Nuclear Regulatory Commission

The NCRP values highly the participation of these organizations in the liaison program.

The Council's activities are made possible by the voluntary contribution of time and effort by its members and participants and the generous support of the following organizations:

Alfred P. Sloan Foundation
Alliance of American Insurers
American Academy of Dental Radiology
American Academy of Dermatology
American Association of Physicists in Medicine
American College of Nuclear Physicians
American College of Radiology
American College of Radiology Foundation
American Dental Association

American Hospital Radiology Administrators
American Industrial Hygiene Association
American Insurance Association
American Medical Association
American Nuclear Society
American Occupational Medical Association
American Public Health Association
American Radium Society
American Roentgen Ray Society
American Society of Radiologic Technologists
American Society for Therapeutic Radiology and Oncology
American Veterinary Medical Association
American Veterinary Radiology Society
Association of University Radiologists
Atomic Industrial Forum
Battelle Memorial Institute
Center for Devices and Radiological Health
College of American Pathologists
Commonwealth of Pennsylvania
Defense Nuclear Agency
Edison Electric Institute
Edward Mallinckrodt, Jr. Foundation
Electric Power Research Institute
Federal Emergency Management Agency
Florida Institute of Phosphate Research
Genetics Society of American
Health Physics Society
Institute of Nuclear Power Operations
James Picker Foundation
Lounsbery Foundation
National Aeronautics and Space Administration
National Association of Photographic Manufacturers
National Bureau of Standards
National Cancer Institute
National Electrical Manufacturers Association
Nuclear Management and Resources Council
Radiation Research Society
Radiological Society of North America
Society of Nuclear Medicine
United States Department of Energy
United States Department of Labor
United States Environmental Protection Agency
United States Navy
United States Nuclear Regulatory Commission

To all of these organizations the Council expresses its profound appreciation for their support.

Initial funds for publication of NCRP reports were provided by a grant from the James Picker Foundation and for this the Council wishes to express its deep appreciation.

The NCRP seeks to promulgate information and recommendations

based on leading scientific judgment on matters of radiation protection and measurements and to foster cooperation among organizations concerned with these matters. These efforts are intended to serve the public interest and the Council welcomes comments and suggestions on its reports or activities from those interested in its work.

NCRP Publications

NCRP publications are distributed by the NCRP Publications' office. Information on prices and how to order may be obtained by directing an inquiry to:

NCRP Publications
7910 Woodmont Ave., Suite 800
Bethesda, Md 20814

The currently available publications are listed below.

Proceedings of the Annual Meeting

No.	Title
1	*Perceptions of Risk,* Proceedings of the Fifteenth Annual Meeting, Held on March 14–15, 1979 (Including Taylor Lecture No. 3) (1980)
2	*Quantitative Risk in Standards Setting,* Proceedings of the Sixteenth Annual Meeting, Held on April 2–3, 1980 (Including Taylor Lecture No. 4) (1981)
3	*Critical Issues in Setting Radiation Dose Limits,* Proceedings of the Seventeenth Annual Meeting, Held on April 8–9, 1981 (Including Taylor Lecture No. 5) (1982)
4	*Radiation Protection and New Medical Diagnostic Procedures,* Proceedings of the Eighteenth Annual Meeting, Held on April 6–7, 1982 (Including Taylor Lecture No. 6) (1983)
5	*Environmental Radioactivity,* Proceedings of the Nineteenth Annual Meeting, Held on April 6–7, 1983 (Including Taylor Lecture No. 7) (1984)
6	*Some Issues Important in Developing Basic Radiation Protection Recommendations,* Proceedings of the Twentieth Annual Meeting, Held on April 4–5, 1984 (Including Taylor Lecture No. 8) (1985)
7	*Radioactive Waste,* Proceedings of the Twenty-first Annual Meeting, Held on April 3–4, 1985 (Including Taylor Lecture No. 9) (1986)
8	*Nonionizing Electromagnetic Radiation and Ultrasound,* Proceedings of the Twenty-second Annual Meeting, Held on April 2–3, 1986 (Including Taylor Lecture No. 10) (1988)

9 *New Dosimetry at Hiroshima and Nagasaki and Its Implications for Risk Estimates,* Proceedings of the Twenty-third Annual Meeting, Held on April 5–6, 1987 (Including Taylor Lecture No. 11) (1988).

10 *Radon,* Proceedings of the Twenty-fourth Annual Meeting, Held on March 30–31, 1988 (Including Taylor Lecture No. 12) (1989).

11 *Radiation Protection Today—The NCRP at Sixty Years,* Proceedings of the Twenty-fifth Annual Meeting, Held on April 5–6, 1989 (Including Lecture No. 13) (1989).

Symposium Proceedings

The Control of Exposure of the Public to Ionizing Radiation in the Event of Accident or Attack, Proceedings of a Symposium held April 27–29, 1981 (1982)

Lauriston S. Taylor Lectures

No.	Title and Author
1	*The Squares of the Natural Numbers in Radiation Protection* by Herbert M. Parker (1977)
2	*Why be Quantitative About Radiation Risk Estimates?* by Sir Edward Pochin (1978)
3	*Radiation Protection—Concepts and Trade Offs* by Hymer L. Friedell (1979) [Available also in *Perceptions of Risk,* see above]
4	*From "Quantity of Radiation" and "Dose" to "Exposure" and "Absorbed Dose"—An Historical Review* by Harold O. Wyckoff (1980) [Available also in *Quantitative Risks in Standards Setting,* see above]
5	*How Well Can We Assess Genetic Risk? Not Very* by James F. Crow (1981) [Available also in *Critical Issues in Setting Radiation Dose Limits,* see above]
6	*Ethics, Trade-offs and Medical Radiation* by Eugene L. Saenger (1982) [Available also in *Radiation Protection and New Medical Diagnostic Approaches,* see above]
7	*The Human Environment-Past, Present and Future* by Merril Eisenbud (1983) [Available also in *Environmental Radioactivity,* see above]
8	*Limitation and Assessment in Radiation Protection* by Harald H. Rossi (1984) [Available also in *Some Issues Important in Developing Basic Radiation Protection Recommendations,* see above]

9 *Truth (and Beauty) in Radiation Measurement* by John H. Harley (1985) [Available also in *Radioactive Waste,* see above]

10 *Nonionizing Radiation Bioeffects: Cellular Properties and Interactions* by Herman P. Schwan (1986) [Available also in *Nonionizing Electromagnetic Radiations and Ultrasound,* see above]

11 *How to be Quantitative about Radiation Risk Estimates* by Seymour Jablon (1987) [Available also in *New Dosimetry at Hiroshima and Nagasaki and its Implications for Risk Estimates,* see above]

12 *How Safe is Safe Enough?* by Bo Lindell (1988) [Available also in *Radon,* see above]

13 *Radiobiology and Radiation Protection: The Past Century and Prospects for the Future* by Arthur C. Upton (1989) [Available also in *Radiation Protection Today—The NCRP at Sixty Years,* see above]

NCRP Commentaries

No.	Title
1	*Krypton-85 in the Atmosphere—With Specific Reference to the Public Health Significance of the Proposed Controlled Release at Three Mile Island* (1980)
2	*Preliminary Evaluation of Criteria for the Disposal of Transuranic Contaminated Waste* (1982)
3	*Screening Techniques for Determining Compliance with Environmental Standards* (1986), Rev. (1989)
4	*Guidelines for the Release of Waste Water from Nuclear Facilities with Special Reference to the Public Health Significance of the Proposed Release of Treated Waste Waters at Three Mile Island* (1987)
5	*Living Without Landfills* (1989)

NCRP Reports

No.	Title
8	*Control and Removal of Radioactive Contamination in Laboratories* (1951)
22	*Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational Exposure* (1959) [Includes Addendum 1 issued in August 1963]
23	*Measurement of Neutron Flux and Spectra for Physical and Biological Applications* (1960)

25 *Measurement of Absorbed Dose of Neutrons and Mixtures of Neutrons and Gamma Rays* (1961)
27 *Stopping Powers for Use with Cavity Chambers* (1961)
30 *Safe Handling of Radioactive Materials* (1964)
32 *Radiation Protection in Educational Institutions* (1966)
35 *Dental X-Ray Protection* (1970)
36 *Radiation Protection in Veterinary Medicine* (1970)
37 *Precautions in the Management of Patients Who Have Received Therapeutic Amounts of Radionuclides* (1970)
38 *Protection Against Neutron Radiation* (1971)
40 *Protection Against Radiation from Brachytherapy Sources* (1972)
41 *Specifications of Gamma-Ray Brachytherapy Sources* (1974)
42 *Radiological Factors Affecting Decision-Making in a Nuclear Attack* (1974)
44 *Krypton-85 in the Atmosphere—Accumulation, Biological Significance, and Control Technology* (1975)
46 *Alpha-Emitting Particles in Lungs* (1975)
47 *Tritium Measurement Techniques* (1976)
49 *Structural Shielding Design and Evaluation for Medical Use of X Rays and Gamma Rays of Energies Up to 10 MeV* (1976)
50 *Environmental Radiation Measurements* (1976)
51 *Radiation Protection Design Guidelines for 0.1–100 MeV Particle Accelerator Facilities* (1977)
52 *Cesium-137 from the Environment to Man: Metabolism and Dose* (1977)
53 *Review of NCRP Radiation Dose Limit for Embryo and Fetus in Occupationally Exposed Women* (1977)
54 *Medical Radiation Exposure of Pregnant and Potentially Pregnant Women* (1977)
55 *Protection of the Thyroid Gland in the Event of Releases of Radioiodine* (1977)
57 *Instrumentation and Monitoring Methods for Radiation Protection* (1978)
58 *A Handbook of Radioactivity Measurements Procedures*, 2nd ed. (1985)
59 *Operational Radiation Safety Program* (1978)
60 *Physical, Chemical, and Biological Properties of Radiocerium Relevant to Radiation Protection Guidelines* (1978)
61 *Radiation Safety Training Criteria for Industrial Radiography* (1978)
62 *Tritium in the Environment* (1979)

63 *Tritium and Other Radionuclide Labeled Organic Compounds Incorporated in Genetic Material* (1979)
64 *Influence of Dose and Its Distribution in Time on Dose-Response Relationships for Low-LET Radiations* (1980)
65 *Management of Persons Accidentally Contaminated with Radionuclides* (1980)
66 *Mammography* (1980)
67 *Radiofrequency Electromagnetic Fields—Properties, Quantities and Units, Biophysical Interaction, and Measurements* (1981)
68 *Radiation Protection in Pediatric Radiology* (1981)
69 *Dosimetry of X-Ray and Gamma-Ray Beams for Radiation Therapy in the Energy Range 10 keV to 50 MeV* (1981)
70 *Nuclear Medicine—Factors Influencing the Choice and Use of Radionuclides in Diagnosis and Therapy* (1982)
71 *Operational Radiation Safety—Training* (1983)
72 *Radiation Protection and Measurement for Low Voltage Neutron Generators* (1983)
73 *Protection in Nuclear Medicine and Ultrasound Diagnostic Procedures in Children* (1983)
74 *Biological Effects of Ultrasound: Mechanisms and Clinical Implications* (1983)
75 *Iodine-129: Evaluation of Releases from Nuclear Power Generation* (1983)
76 *Radiological Assessment: Predicting the Transport, Bioaccumulation, and Uptake by Man of Radionuclides Released to the Environment* (1984)
77 *Exposures from the Uranium Series with Emphasis on Radon and its Daughters* (1984)
78 *Evaluation of Occupational and Environmental Exposures to Radon and Radon Daughters in the United States* (1984)
79 *Neutron Contamination from Medical Electron Accelerators* (1984)
80 *Induction of Thyroid Cancer by Ionizing Radiation* (1985)
81 *Carbon-14 in the Environment* (1985)
82 *SI Units in Radiation Protection and Measurements* (1985)
83 *The Experimental Basis for Absorbed-Dose Calculations in Medical Uses of Radionuclides* (1985)
84 *General Concepts for the Dosimetry of Internally Deposited Radionuclides* (1985)
85 *Mammography—A User's Guide* (1986)
86 *Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields* (1986)

87 *Use of Bioassay Procedures for Assessment of Internal Radionuclide Deposition* (1987)
88 *Radiation Alarms and Access Control Systems* (1987)
89 *Genetic Effects of Internally Deposited Radionuclides* (1987)
90 *Neptunium: Radiation Protection Guidelines* (1987)
91 *Recommendations on Limits for Exposure to Ionizing Radiation* (1987)
92 *Public Radiation Exposure from Nuclear Power Generation in the United States* (1987)
93 *Ionizing Radiation Exposure of the Population of the United States* (1987)
94 *Exposure of the Population in the United States and Canada from Natural Background Radiation* (1987)
95 *Radiation Exposure of the U.S. Population from Consumer Products and Miscellaneous Sources* (1987)
96 *Comparative Carcinogenesis of Ionizing Radiation and Chemicals* (1989)
97 *Measurement of Radon and Radon Daughters in Air* (1988)
98 *Guidance on Radiation Received in Space Activities* (1989)
99 *Quality Assurance for Diagnostic Imaging* (1988)
100 *Exposure of the U.S. Population from Diagnostic Medical Radiation* (1989)
101 *Exposure of the U.S. Population From Occupational Radiation* (1989)
102 *Medical X-Ray, Electron Beam and Gamma-Ray Protection For Energies Up To 50 MeV (Equipment Design, Performance and Use)* (1989)
103 *Control of Radon in Houses* (1989)
105 *Radiation Protection for Medical and Allied Health Personnel* (1989)
106 *Limit of Exposure to "Hot Particles" on the skin* (1989)

Binders for NCRP Reports are available. Two sizes make it possible to collect into small binders the "old series" of reports (NCRP Reports Nos. 8–30) and into large binders the more recent publications (NCRP Reports Nos. 32–106). Each binder will accommodate from five to seven reports. The binders carry the identification "NCRP Reports" and come with label holders which permit the user to attach labels showing the reports contained in each binder.

The following bound sets of NCRP Reports are also available:

Volume I. NCRP Reports Nos. 8, 22
Volume II. NCRP Reports Nos. 23, 25, 27, 30
Volume III. NCRP Reports Nos. 32, 35, 36, 37

Volume IV. NCRP Reports Nos. 38, 40, 41
Volume V. NCRP Reports Nos. 42, 44, 46
Volume VI. NCRP Reports Nos. 47, 49, 50, 51
Volume VII. NCRP Reports Nos. 52, 53, 54, 55, 57
Volume VIII. NCRP Reports No. 58
Volume IX. NCRP Reports Nos. 59, 60, 61, 62, 63
Volume X. NCRP Reports Nos. 64, 65, 66, 67
Volume XI. NCRP Reports Nos. 68, 69, 70, 71, 72
Volume XII. NCRP Reports Nos. 73, 74, 75, 76
Volume XIII. NCRP Reports Nos. 77, 78, 79, 80
Volume XIV. NCRP Reports Nos. 81, 82, 83, 84, 85
Volume XV. NCRP Reports Nos. 86, 87, 88, 89
Volume XVI. NCRP Reports Nos. 90, 91, 92, 93
Volume XVII. NCRP Reports Nos. 94, 95, 96, 97

(Titles of the individual reports contained in each volume are given above).

The following NCRP Reports are now superseded and/or out of print:

No.	Title
1	*X-Ray Protection* (1931). [Superseded by NCRP Report No. 3]
2	*Radium Protection* (1934). [Superseded by NCRP Report No. 4]
3	*X-Ray Protection* (1936). [Superseded by NCRP Report No. 6]
4	*Radium Protection* (1938). [Superseded by NCRP Report No. 13]
5	*Safe Handling of Radioactive Luminous Compounds* (1941). [Out of Print]
6	*Medical X-Ray Protection Up to Two Million Volts* (1949). [Superseded by NCRP Report No. 18]
7	*Safe Handling of Radioactive Isotopes* (1949). [Superseded by NCRP Report No. 30]
9	*Recommendations for Waste Disposal of Phosphorus-32 and Iodine-131 for Medical Users* (1951). [Out of Print]
10	*Radiological Monitoring Methods and Instruments* (1952). [Superseded by NCRP Report No. 57]
11	*Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water* (1953). [Superseded by NCRP Report No. 22]
12	*Recommendations for the Disposal of Carbon-14 Wastes* (1953). [Superseded by NCRP Report No. 81]

13 *Protection Against Radiations from Radium, Cobalt-60 and Cesium-137* (1954). [Superseded by NCRP Report No. 24]

14 *Protection Against Betatron—Synchrotron Radiations Up to 100 Million Electron Volts* (1954). [Superseded by NCRP Report No. 51]

15 *Safe Handling of Cadavers Containing Radioactive Isotopes* (1953). [Superseded by NCRP Report No. 21]

16 *Radioactive Waste Disposal in the Ocean* (1954). [Out of Print]

17 *Permissible Dose from External Sources of Ionizing Radiation* (1954) including *Maximum Permissible Exposure to Man, Addendum to National Bureau of Standards Handbook 59* (1958). [Superseded by NCRP Report No. 39]

18 *X-Ray Protection* (1955). [Superseded by NCRP Report No. 26]

19 *Regulation of Radiation Exposure by Legislative Means* (1955). [Out of Print]

20 *Protection Against Neutron Radiation Up to 30 Million Electron Volts* (1957). [Superseded by NCRP Report No. 38]

21 *Safe Handling of Bodies Containing Radioactive Isotopes* (1958). [Superseded by NCRP Report No. 37]

24 *Protection Against Radiations from Sealed Gamma Sources* (1960). [Superseded by NCRP Report Nos. 33, 34, and 40]

26 *Medical X-Ray Protection Up to Three Million Volts* (1961). [Superseded by NCRP Report Nos. 33, 34, 35, and 36]

28 *A Manual of Radioactivity Procedures* (1961). [Superseded by NCRP Report No. 58]

29 *Exposure to Radiation in an Emergency* (1962). [Superseded by NCRP Report No. 42]

31 *Shielding for High Energy Electron Accelerator Installations* (1964). [Superseded by NCRP Report No. 51]

33 *Medical X-Ray and Gamma-Ray Protection for Energies up to 10 MeV*—Equipment Design and Use (1968). [Superseded by NCRP Report No. 102]

34 *Medical X-Ray and Gamma-Ray Protection for Energies Up to 10 MeV—Structural Shielding Design and Evaluation* (1970). [Superseded by NCRP Report No. 49]

39 *Basic Radiation Protection Criteria* (1971). [Superseded by NCRP Report No. 91]

43 *Review of the Current State of Radiation Protection Philosophy* (1975). [Superseded by NCRP Report No. 91]

45 *Natural Background Radiation in the United States* (1975). [Superseded by NCRP Report No. 94]

48 *Radiation Protection for Medical and Allied Health Personnel* [Superseded by NCRP Report No. 105]

56 *Radiation Exposure from Consumer Products and Miscellaneous Sources* (1977). [Superseded by NCRP Report No. 95]

58 *A Handbook on Radioactivity Measurement Procedures.* [Superseded by NCRP Report No. 58, 2nd ed.]

Other Documents

The following documents of the NCRP were published outside of the NCRP Reports and Commentaries series:

"Blood Counts, Statement of the National Committee on Radiation Protection," Radiology 63, 428 (1954)

"Statements on Maximum Permissible Dose from Television Receivers and Maximum Permissible Dose to the Skin of the Whole Body," Am. J. Roentgenol., Radium Ther. and Nucl. Med. 84, 152 (1960) and Radiology 75, 122 (1960)

Dose Effect Modifying Factors In Radiation Protection, Report of Subcommittee M-4 (Relative Biological Effectiveness) of the National Council on Radiation Protection and Measurements, Report BNL 50073 (T-471) (1967) Brookhaven National Laboratory (National Technical Information Service, Springfield, Virginia).

X-Ray Protection Standards for Home Television Receivers, Interim Statement of the National Council on Radiation Protection and Measurements (National Council on Radiation Protection and Measurements, Washington, 1968)

Specification of Units of Natural Uranium and Natural Thorium (National Council on Radiation Protection and Measurements, Washington, 1973)

NCRP Statement on Dose Limit for Neutrons (National Council on Radiation Protection and Measurements, Washington, 1980)

Control of Air Emissions of Radionuclides (National Council on Radiation Protection and Measurements, Bethesda, Maryland, 1984)

Copies of the statements published in journals may be consulted in libraries. A limited number of copies of the remaining documents listed above are available for distribution by NCRP Publications.

Index

Artifacts, 183–185
  caused by improper use of imaging equipment, 184–185
  from overlying objects, 183–184

Capacitor discharge systems, 99–100
Cardiac radiology, 171
  video systems, 171
Cinefluorographic units, 118–119
Clutter (see Spatial resolution)
Computed tomography, 120–124, 171
  CT number, 121–122
  patient dosimetry, 123
  quantitative CT, 124
  table, 123
  visual output, 122–123
  video systems, 171
Computers, 180–182
Conventional fluoroscopy, 171
  video systems, 171
Conventional radiography, 61–83
  cassettes, screens, films, and chemicals, 78–81
  exposure per unit of tube current and time, 72
  exposure reproducibility, 73–74
  exposure timers, 70–71
  film evaluation following radiograph of a phantom, 81
  grids, 76–78
  linearity, 72–73
  peak generating potential (kVp), 69–70
  phototimers, 74–76
  x-ray (radiation) output waveforms, 71–72
  x-ray generators, 68–76
  x-ray tubes and collimators, 61–68
Conventional x-ray tomography, 104–106
Cost-benefit considerations, 9–11

Dental radiography, 111-116
  beam alignment and collimation, 115
  beam quality, 115
  cassette and screen, 114
  darkroom, 113
  exposure switch, 115
  film processing, 113
  leakage radiation, 114
  radiation exposure, 115–116
  reference film, 111
  retake record, 112–113
  source to end-of-cone distance, 115
  test film, 111–112
  test radiograph, 112
  timer, 115
  viewboxes, 114
Diagnostic ultrasound, 153–166
  acoustical exposure measurements, 166
  care and maintenance, 165–166
  operator training, 165–166
  pulse-echo scanners, 153, 156–162
  ultrasound B-mode images, 153–156
  ultrasound Doppler, 164–165
  video systems, 171
Digital imaging, 125–127
  control limits, 127
  digital subtraction angiographic imaging, 125–127
  exposure measurements, 126
  patient-equivalent phantom, 126
  resolution pattern, 126
  step wedge, 126
Digital radiography, 171
  video systems, 171
Digital recorders, 177–179
Digital subtraction angiographic imaging, 125–127

Education and quality assurance, 11–13

Film changers, 117–118
Film evaluation following radiograph of a phantom, 81–83
  exposure per film, 81–82
  matching images and exposures, 83
Fluoroscopic and cine imaging quality control, 84–98
  automatic brightness, exposure, and gain control systems, 89–90
  cine projectors, 98

exposure rates and exposure, 85–89
flare, 94–96
image lag, 93–94
image size and beam limitation, 90–91
relative conversion factor of image intensifiers, 96–97
resolution and distortion, 91–93
spot film, 90–91
x-ray tubes, collimators, and generators, 85
Fluoroscopic systems, 84–99, 102–103, 171
mobile, 99, 102–103
video systems, 171

General objectives, 5–8
accuracy in diagnosis, 5–6
communication, 7–8
cost, 8
minimizing radiation per examination, 6–7
provisions for comfort of the patient, 7
Grids, 76–78

Hard copy cameras, 174–177

Image intensifiers, 96–97
Imaging accessories, 145
Imaging physician's reading room, 186–187
illumination intensity, 186
motorized film viewers, 186–187
Index of compliance, 16–17
incident report, 16
patient's film jacket, 17
report of the interpretation of an imaging study, 16
request form, 16
room log, 16

Laser cameras, 174

Magnetic resonance imaging (MRI), 167–170, 171
geometric distortion, 167
high contrast, 169–170
phantoms, 169
relaxation times, 167, 169
signal-to-noise ratio, 167–168
slice position to patient position relationship, 167
slice profile, 167
slice spacing, 167
slice thickness, 167
spatial uniformity of signal, 167
video systems, 171
Mammography, 108–110
Mechanical safety, 185–186
M-Mode systems, 162-163
distance calibration accuracy, 162, 163
sensitivity, 163
time markers, 162–163
Mobile radiographic systems, 99–102
Mobile fluoroscopic systems, 99, 102, 103
Multiformat camera, 145

Nonimaging scintillation systems, 136–137
geometry effects, 137
precision, 137
Nuclear medicine, 128–152
electrical power, 128
imaging accessories, 145
multiformat camera, 145
nonimaging scintillation systems, 136–137
radionuclide calibrator, 129–132
records, 129
rectilinear scanners, 137–139
scintillation cameras, 139–145
scintillation spectrometer, 132–136
single photon emission computed tomography (SPECT), 145–150
survey meters, 151–152
xenon trapping systems, 150–151

Performance optimization, 31–43
management of personnel activities, 31–43
Personnel performance, 14–16
establishing policies, 15–16
Photographic quality control, 44–60
darkroom, 45–48
film copiers, 59–60
processing conditions, 46–47
processor quality control, 48–55
special systems, 55–59
storage, 44–45
Pulse echo response widths (see Spatial resolution)
Pulse-echo scanners, 153, 156–162
geometric accuracy, 153
hard copy recording, 158–159

image display characteristics, 162
image uniformity, 158
maximum system sensitivity, 156
maximum depth of visualization, 157
routine sensitivity checks, 157
spatial resolution, 159
system sensitivity, 156

Quality assurance, 1–8, 14
approaches, 4
content, 2–3
costs and benefits, 2
definition, 1
equipment factors, 5
general concepts, 4
general objectives, 5–8
goal, 4
human factors, 4–5
implementation, 2
motivation, 1
personnel performance, 14
records keeping, 14
Quality assurance committee, 19–20
Quality assurance program, 20–21
evaluation of the findings, 20
index of compliance, 16–19
institution of corrective action, 20
Quality control program, 22–30
acceptance testing, 22
administrative organization, 22
diagnosis of changes, 22
establishment of, 22
establishment of baseline performance, 22
exposure per image, 29–30
general methodology, 26
recording equipment downtime and failure, 29
responsibility, 23
retake analysis, 26–29
test objects for, 30
tools needed, 26
verification of correction of causes of deterioration, 22
Quality of images, 8–9
definition of image quality, 8–9

Radiological special procedures, 117–119
cinefluorographic units, 118–119
film changers, 117–118
Radionuclide calibrator, 129–132
accuracy, 131
geometry effects, 131–132
linearity of response, 130–131
relative response to reference source, 130
test precision, 129–130
Record keeping, 14, 16–20
analyzing the records, 18–19
index of compliance, 16–17
quality assurance committee, 19–20
Rectilinear scanners, 137–139
collimator evaluation, 139
contrast enhancement, 138
density calibration, 138–139
precision, 138
Resolution cell, 160

Scintillation cameras, 139–145
counting rate characteristics, 144
energy resolution, 144–145
relative sensitivity, 140, 144
spatial linearity, 140, 142–143
spatial resolution, 140, 142–143
uniformity, 140–142
Scintillation spectrometer, 132–136
60-herz test, 132
background activity check, 133
chi-square test, 134
counting rate effects, 136
energy calibration, 134–135
energy resolution, 135
linearity, 135–136
precision, 133
pulse height analyzer, 132–133
Single photon emission computed tomography (SPECT), 145–150
camera axis of rotation plane alignment, 148
camera-computer system, 149
center-of-rotation determination, 147
field uniformity, 146
phantoms, 149–150
pixel sizing, 147–148
spatial resolution, 148–149
Slice thickness, 159 (see Spatial resolution)
Spatial resolution, 159–161
axial resolution, 159–161
elevational resolution, 159–161
lateral resolution, 159–161
Survey meters, 151–152
calibration, 151
constancy, 151–152

Ultrasonic doppler systems, 164–165
accuracy of flow readout, 164–165
noise level, 164
range gate accuracy, 165
signal sensitivity, 164
Ultrasound (see diagnostic ultrasound)
Ultrasound B-mode images, 153–156
compound scan registration, 154–155
depth calibration, 154
externally referenced measurement, 155–156
geometric accuracy, 153–156
horizontal measurement, 154
Video disc recorders, 177–179
Video systems, 171–174
line termination, 171–172
RS-170 broadcast standard, 171
television monitors, 171–174
video signal levels, 171
video termination, 171–172
video waveform monitor, 172
visual displays, 174
Video tape recorders, 177–179

Xenon trapping system, 150
exhaust check, 150
X-ray generators, 68–76
X-ray tubes and collimators, 61–68

http://nihlibrary.nih.gov

10 Center Drive
Bethesda, MD 20892-1150
301-496-1080

NIH LIBRARY
3 1496 00681 2757

JUN 23 2004
SEP 30 2004
JUL 12 2004
JUL 26 2004
AUG 30 2004